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Pumped Spoiling Experimental Program

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PUMPED SPOILING EXPERIMENTAL PROGRAM

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Sandia Contract No. 56-6123

ABSTRACT

This report documents a series of wind tunnel tests on a sample airfoil designed to evaluate and quantify the "pumped spoiling" concept. The test airfoil was a Sandia National Laboratories natural laminar flow section designated SAND-1850. All tests were operated at a Reynolds Number of 1.5 million with a model having a 1-ft chord and a 9-ft span. The spoiling perforations consisted of 1.6-mm diameter holes on 6.35-mm centers. The pressure in the internal plenum that supplied the spoiling air to the perforations was maintained at the tunnel dynamic head. Test results were consistent and repeatable. Up to an angle of attack of 6°, there was very little difference in the lift coefficient among the many test arrangements studied. Past 8°, however, the lift coefficient trends were very sensitive to the test configuration of the model. The report includes the test results for 32 combinations of the spoiling arrangements ranging from "clean" baseline airfoil to spoiling flow through all perforations. In addition to the section coefficients, the report presents model force data and section pressure profiles.

CONTENTS

1.0 INTRODUCTION

1.1 Pumped Spoiling

Power associated with wind energy is proportional to the wind speed cubed. This power yields the characteristic wind energy conversion power curve. Of key interest, from the control perspective, is the high wind-speed zone of the power curve. Provisions must be made for rotor speed regulation and in extreme cases, when winds exceed a given maximum value, for rotor shutdown.

When the energy conversion question is broadened to include the economics of power generation, the situation becomes more complex. On initial inspection, it may be deduced that the rotor, generator, and support system should be designed to extract energy up to the maximum local wind speeds. Closer scrutiny, however, reveals that maximum wind velocities, although representing significant energy levels, are available for only short periods of time. Thus, a wind conversion system designed for maximum wind speeds carries with it economic burdens of higher capacity generators and support structures. Hence, an economically competitive system must have the capability to shed power past a certain rated value.

In the case of horizontal axis wind turbines (HAWTs), the regulation, control, and eventual rotor shutdown often is achieved via some form of blade-pitch change. This, in effect, controls the aerodynamic power input into the turbine proper.

Unfortunately, this solution necessitates complex pitch-change mechanisms and brings with it the associated problems of maintenance and reliability. There are various efforts directed at "spoiling" the flow on the blades of HAWTs by deployment of aerodynamic spoilers. There is some evidence, however, that the combination of a deployed spoiler and high blade angle of attack "fools" the free-stream into thinking that aerodynamic surface is a "thick" airfoil. This has the opposite effect to that desired. The lift coefficient may increase.

The vertical axis wind turbine (VAWT) has its own unique operating and control characteristics. Although auxiliary means must be employed for startup, the rotor requires special treatment for regulation at the upper speeds. Unfortunately, the Darrieus VAWT does not lend itself readily to control by blade-pitch-change mechanisms. Even if blade-pitch change were possible, the blade angles would have to be controlled as a function of the azimuth angle, a situation similar to the cyclic control of helicopter rotors. Finally, the pitch-change mechanisms and structure would have to carry the full-rated torques of the turbine.

The problem of VAWT overspeed control is particularly onerous. Fundamentally, there are two solution paths: mechanical rotor braking and aerodynamic spoiling and braking. The first has been applied on a number of commercial installations. Although this concept leaves the aerodynamics of the turbine in its original simplicity, it introduces a requirement for multiple redundancy in the rotor-brake system.

The concept of spoilers has been developed to a high degree in the aviation industry. Spoiling is a common lift-control mechanism on high-performance sailplanes and in at least one case is the sole source of roll control forces, completely replacing the conventional ailerons.

The preceding techniques are specifically intended for rotor overspeed control. It may be possible to achieve rotor power regulation with partial spoiler deployment. The key benefit to spoiling is that the energy is shed at the blade surface and not at the hub, as is the case with braking.

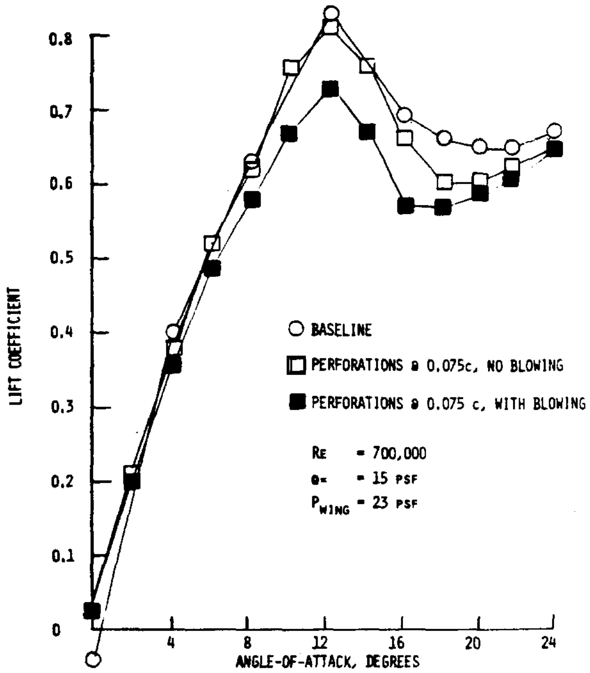
A concept original to Sandia National Laboratories is a form of aerodynamic spoiling that depends on the disruption of the blade surface flow by a series of air jets supplied from the interior of the blade. The rotor regulation is achieved via two different but interdependent principles. The hollow passages of the rotor blades serve as air-pumping channels. If the root of the blade is opened, air will be pumped to the VAWT equator. There it will exit through a series of holes, disrupting the blade aerodynamics. In the first instance, energy is required to pump the blade air. This in itself will decrease power seen at the turbine mast. The jets will in turn alter the blade pressure distribution and decrease the aerodynamic power developed on the blades. Preliminary calculations indicate that the spoiling mechanism rather than the pumping will dominate in the power regulation of the rotor.

1.2 Test Programs

The pumped spoiling concept was initially validated by Sandia National Laboratories on the 5-meter research wind turbine. Reductions in rated power of 15% were measured with all blade ends open. No difference in performance when compared to the baseline turbine was noted with ends closed.

A follow-on program was established at the University of Washington and tests were performed on a sample 1-foot chord x 9-foot span airfoil. The blade profile was a special natural laminar flow section designated SAND-1850. The goal of the test was to ascertain the effect the perforations or apertures have on the lift and drag of the test article. To this end a series of perforations was made at 30, 50, and 70% chord. The perforations consisted of a series of holes 1.6 mm in diameter on 6.35-mm centers drilled full span on both top and bottom surfaces. Air was supplied to the hollow interior of the blade and lift and drag were measured with and without blowing (spoiling). No perceptible evidence of an effect on the lift and drag coefficients could be found with the perforations located at the above chord stations.

This aspect of the performance was attributed to the type of airfoil section under test. The SAND-1850 is a 50% chord laminar flow airfoil and as such maintains a near zero pressure gradient from just aft of the leading edge to approximately mid-chord. Subsequently a row of spoiling perforations was drilled on the top surface at 7.5% chord. The difference in lift coefficient with and without spoiling (blowing) was dramatic. Figure 1 illustrates that the nominal maximum lift coefficient decreases by approximately 10%. These early results largely confirmed that the pumped spoiling perforations would have to be relatively near the leading edge in order to effectively control the lift and drag performance of the airfoil.



Measured lift coefficients on a rectangular wing, AR = 9, using a SAND 0018/50 airfoil with 1.60 mm x 6.35 mm perforations (one side), no tare corrections.

FIGURE 1: PRELIMINARY UNCORRECTED TESTS

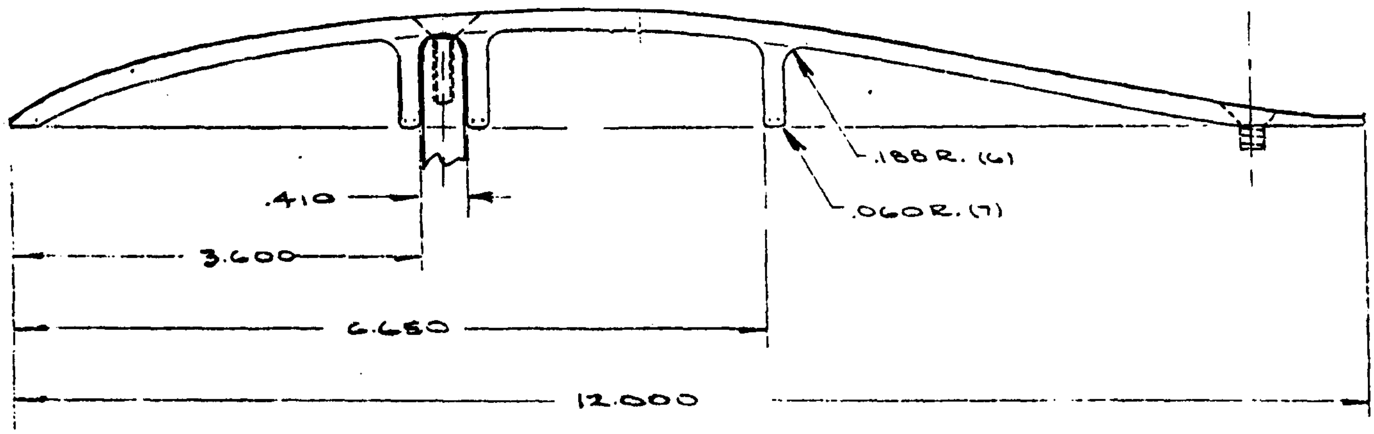


FIGURE 2: DETAILS OF AIRFOIL EXTRUSION (2 REQUIRED)

The present report builds on the above mentioned previous work. It is specifically designed to yield a firm data base to be used in a centrifugally pumped spoiling vertical axis wind turbine power-control system. Obviously, as a result of the earlier tests, the key focus of interest is the near leading edge of the airfoil. The present series of tests was performed on the same test airfoil used in the University of Washington tests, but reconfigured to resolve earlier discrepancies associated with instrumentation and "blowing" air ducting. The detailed statement of work originated by the sponsor is contained in Appendix A.1.

2.0 EXPERIMENTAL TEST PROGRAM

2.1 Test Item Modification

Sandia National Laboratories supplied the test airfoil and it was reconfigured to satisfy the contract statement of work and to better isolate the airfoil from the air supply system. The former involved redrilling a new set of perforations at 3.8% and 7.5% chord, installing surface pressure taps as specified in Table I, and using instrumentation to measure internal pressure in the front plenum of the model. The latter focused on redesigning the air supply system in order to decouple the force input as the supply ducting internal pressure changed. In addition the model was refurbished, and new tip end plates were designed, manufactured, and fitted.

The baseline model consists of two half sections split on the symmetrical chord line (Figure 2). The test article was assembled by bolting two of the extrusions to spacer blocks in the front spar webs and directly through the trailing edge skins. The bolt heads were then faired in with "Klax." To insure safety and structural integrity the mounting points were reinforced by backup "demi" spars in the region of the dynamometer attachment blocks. The perforations from the previous tests at 30, 50, and 70% chord were sealed from the inside by nylon tape.

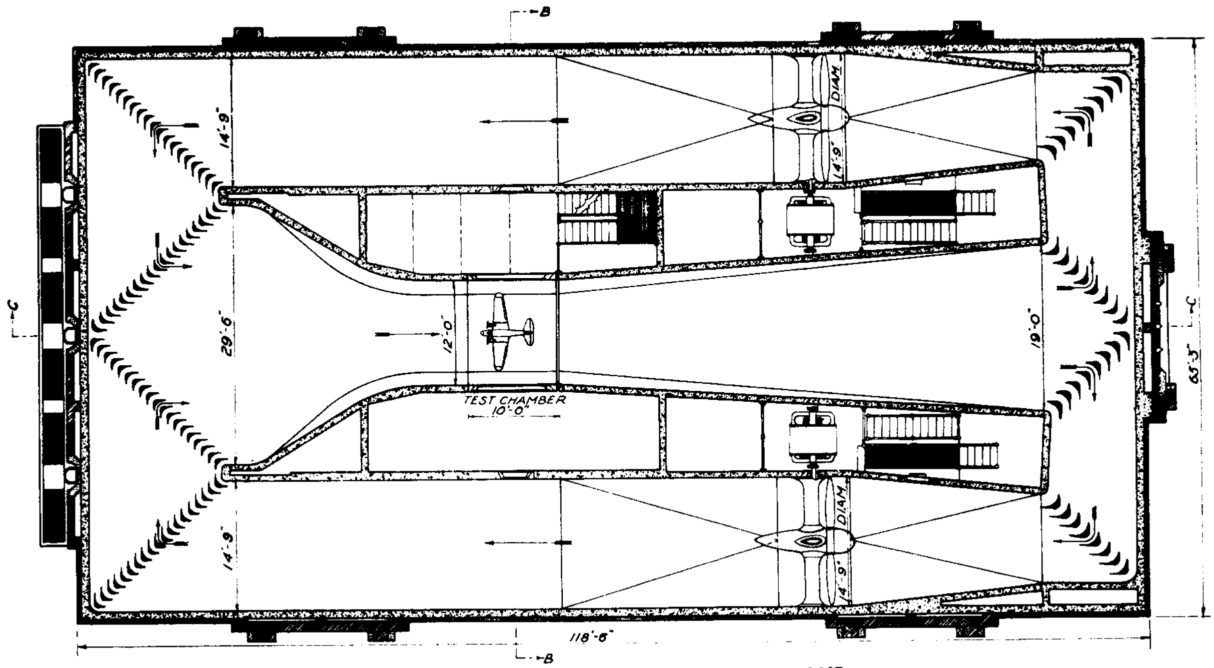
2.2 Facilities and Installation

The test program was conducted in the 8 x 12 ft. subsonic wind tunnel at the University of Washington (Figure 3). The test section has centerline dimensions of 8 ft. high and 12 ft. wide. The section has 18-in. fillets in each corner (Figure 4). The model is normally mounted on the force dynamometer via a mounting fork and a pitch change horn (Figure 5). Because of the airtight

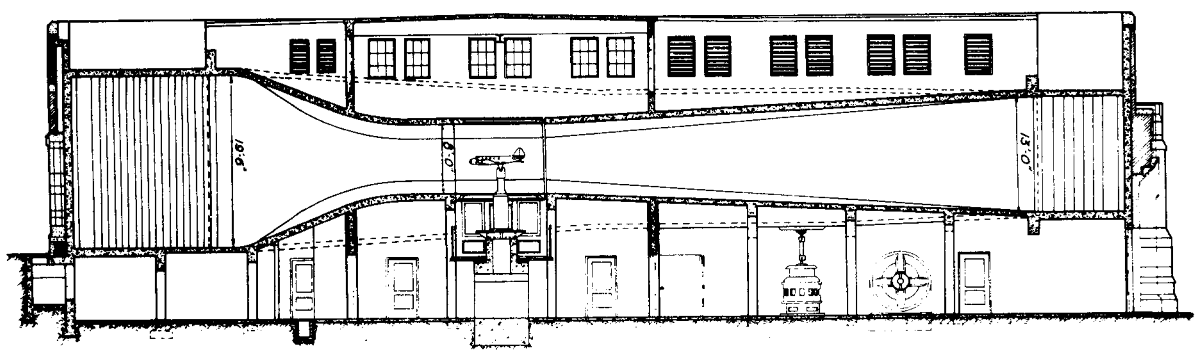
TABLE I

SURFACE PRESSURE TAP LOCATIONS

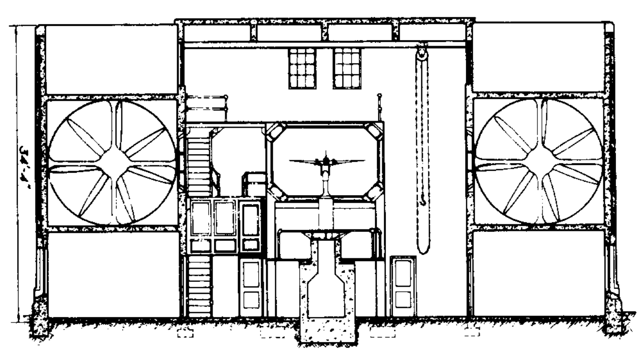
Station	% Chord (Top & Bottom)
0	0 Leading Edge
1	2.5
2	3.8 First Row Perforations
3	5.0
4	7.5 Second Row Perforations
6	10
7	15
8	20
9	25
10	30
11	35
12	40
13	50
14	70
15	80
16	90 Not Operative



SECTIONAL PLAN THRU TUNNEL AXIS



SECTIONAL ELEVATION "C"



SECTIONAL ELEVATION "B"

FIGURE 3 UNIVERSITY OF WASHINGTON — 250 MPH WIND TUNNEL

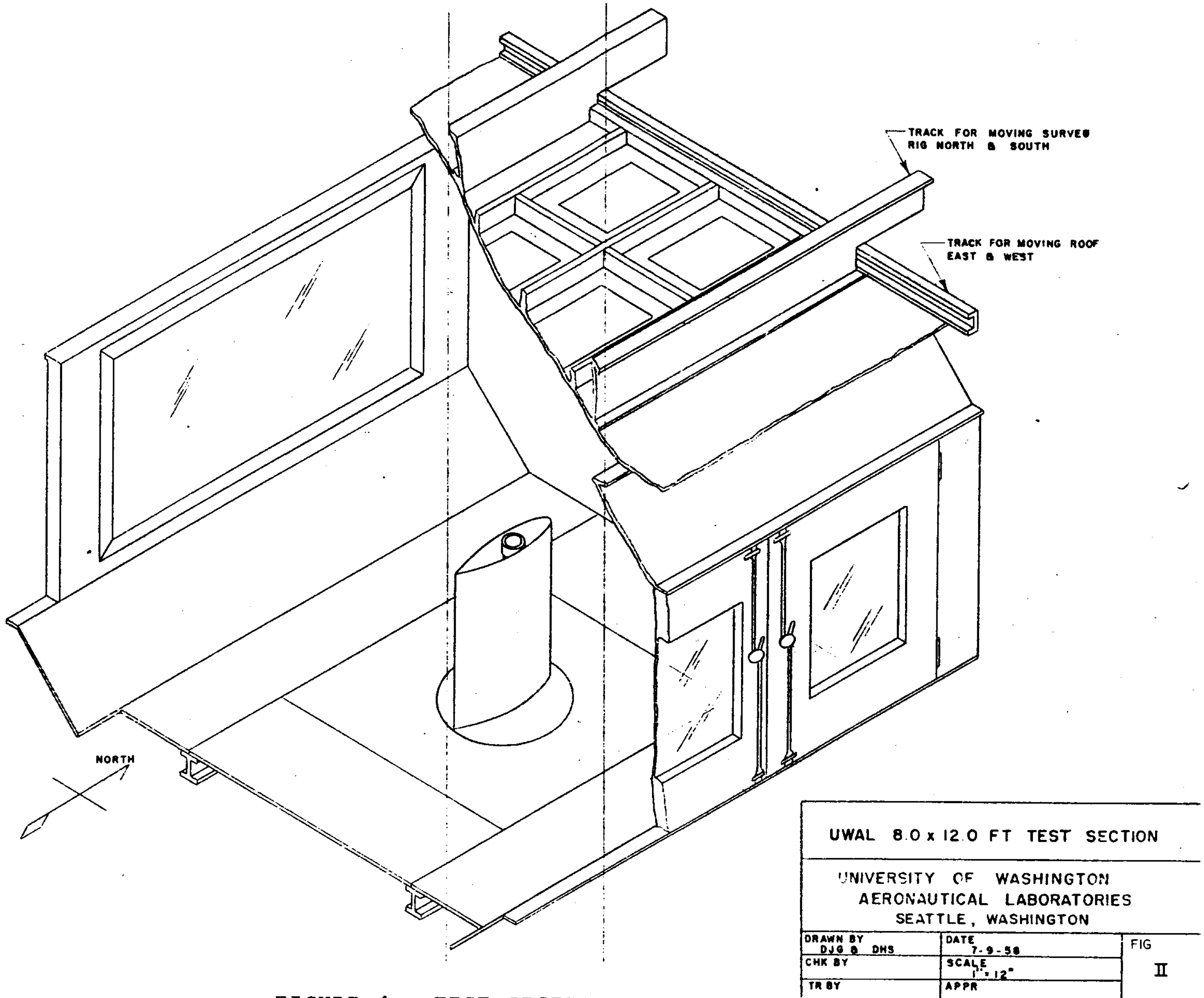
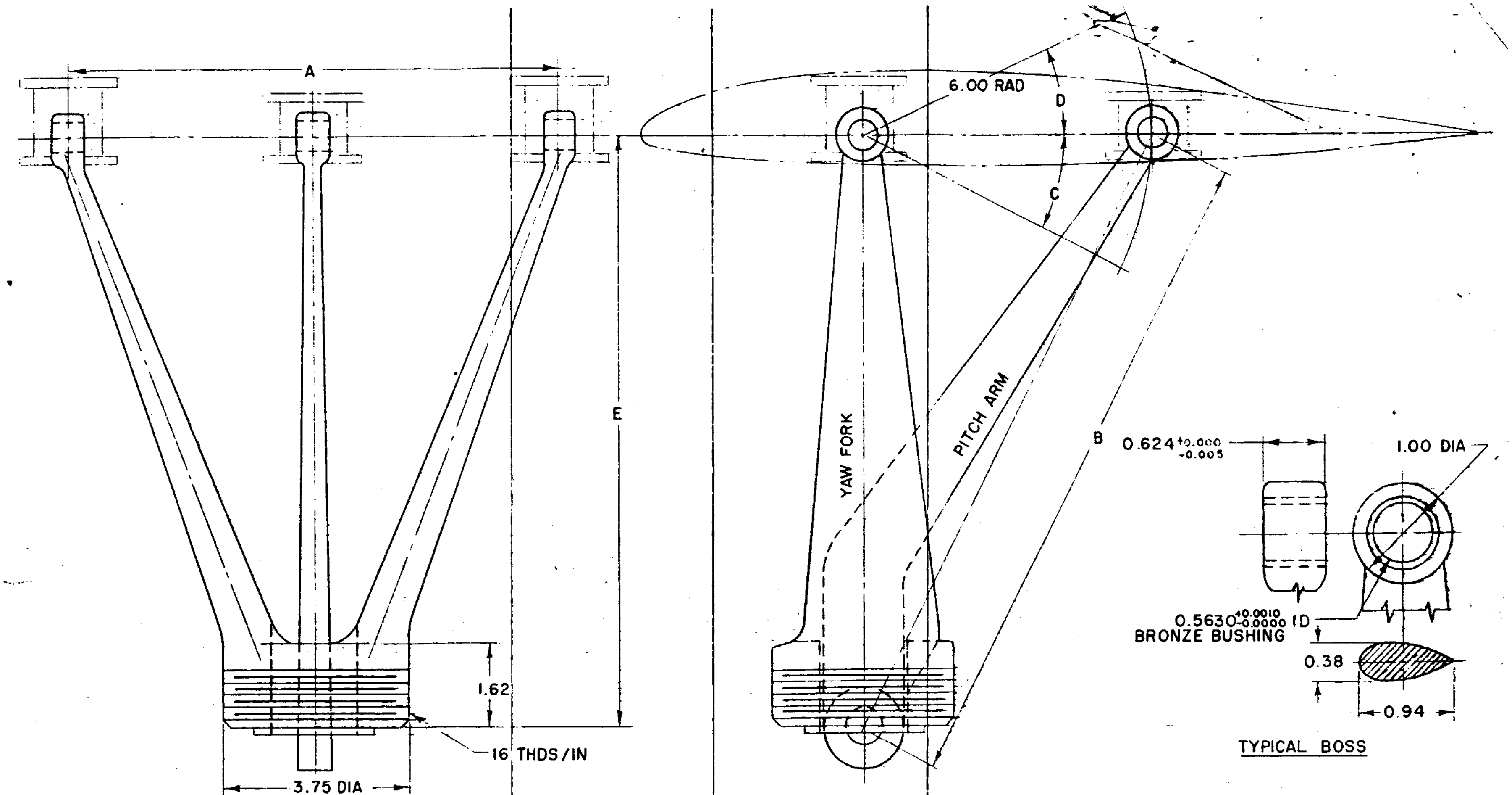


FIGURE 4: TEST SECTION DETAILS



YAW FORK	A	E
5-H	5.0	16.72
10-H	10.0	16.72
14-H	14.0	16.72
5-L	5.0	11.72
10-L	10.0	11.72

PITCH ARM	B	C	D	YAW FORKS
1	17.0	27°	39°	5-H, 10-H, 14-H
2	16.0	37°	24°	5-H, 10-H, 14-H
3	12.66	21°	44°	5-L, 10-L
4	12.0	30°	33°	5-L, 10-L

UWAL MODEL MOUNTING FORKS

UNIVERSITY OF WASHINGTON
AERONAUTICAL LABORATORIES
SEATTLE WASHINGTON

DRAWN BY D H SEIVENO	SCALE HALF SIZE	FIG
CHK BY	DATE 7-3-58	IV
TR BY	APPR	

FIGURE 5: TEST ITEM MOUNTING FORKS

requirements of the front plenum in the model it was necessary to support the model via a pair of mounting blocks, as shown in Figures 6 and 7. The control horn was similarly attached to the model.

In order to isolate the model from spurious force inputs due to air supply ducting and pressure tap lines a pair of ½-in. thick end plates were mounted on the tunnel walls. The 2-ft^2 end plates were supported by vertical stantions and adjustable lead screws. Thus the clearance between the wing tip plate and the Plexiglas end plate could be held to approximately 1/8 in. In addition the end plates provide a degree of two dimensionality in the wing tip area.

The geometry of the model support arrangement resulted in model motion range as depicted in Figure 8. The angle-of-attack range of 0 to 24 degrees yields an area (shaded zone) on the section profile that is fixed relative to the tunnel-mounted end plates. It is through this common area that the blowing air is introduced to the model on one tip, and pressure tap lines lead out at the other. Figure 9 illustrates the air supply scheme. The air supply line is hard wired to the fixed end plate. The air then is transferred to the model across the model-end plate clearance via a soft fabric flexible seal. The pressure tap lines are conducted out the other end again via the common area (Figure 10). A shield is provided to minimize the drag of the pressure tubing bundle where it is exposed to the free stream.

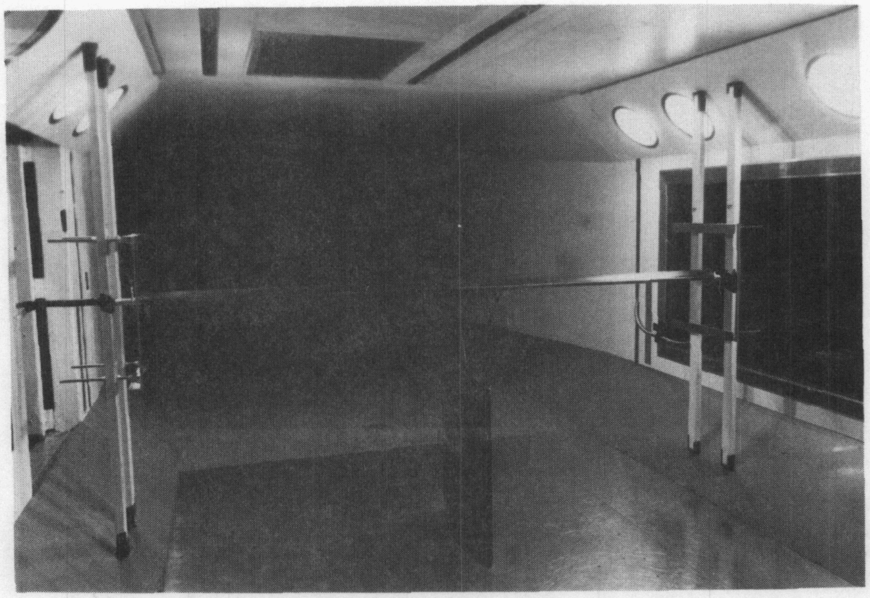


FIGURE 6: TEST AIRFOIL IN WIND TUNNEL

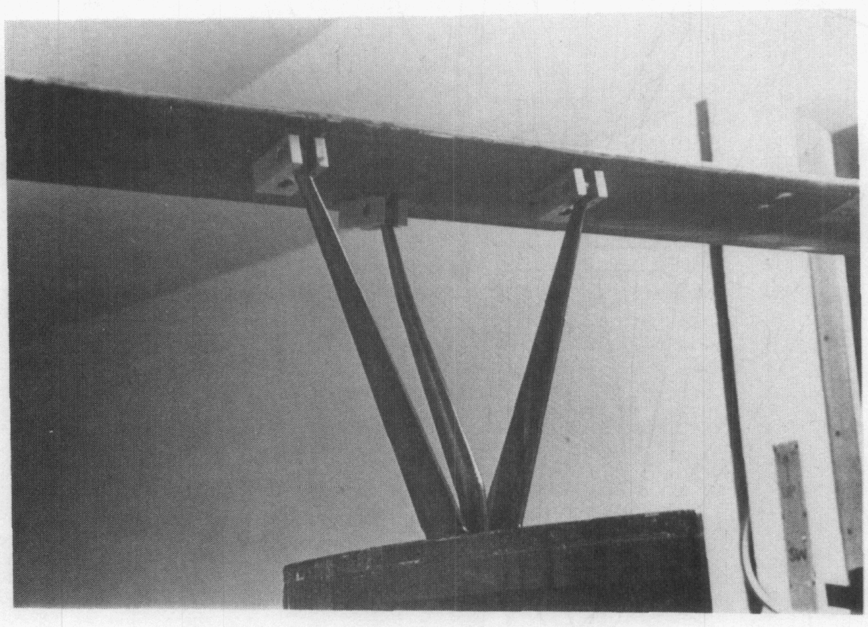


FIGURE 7: SUPPORT DETAIL

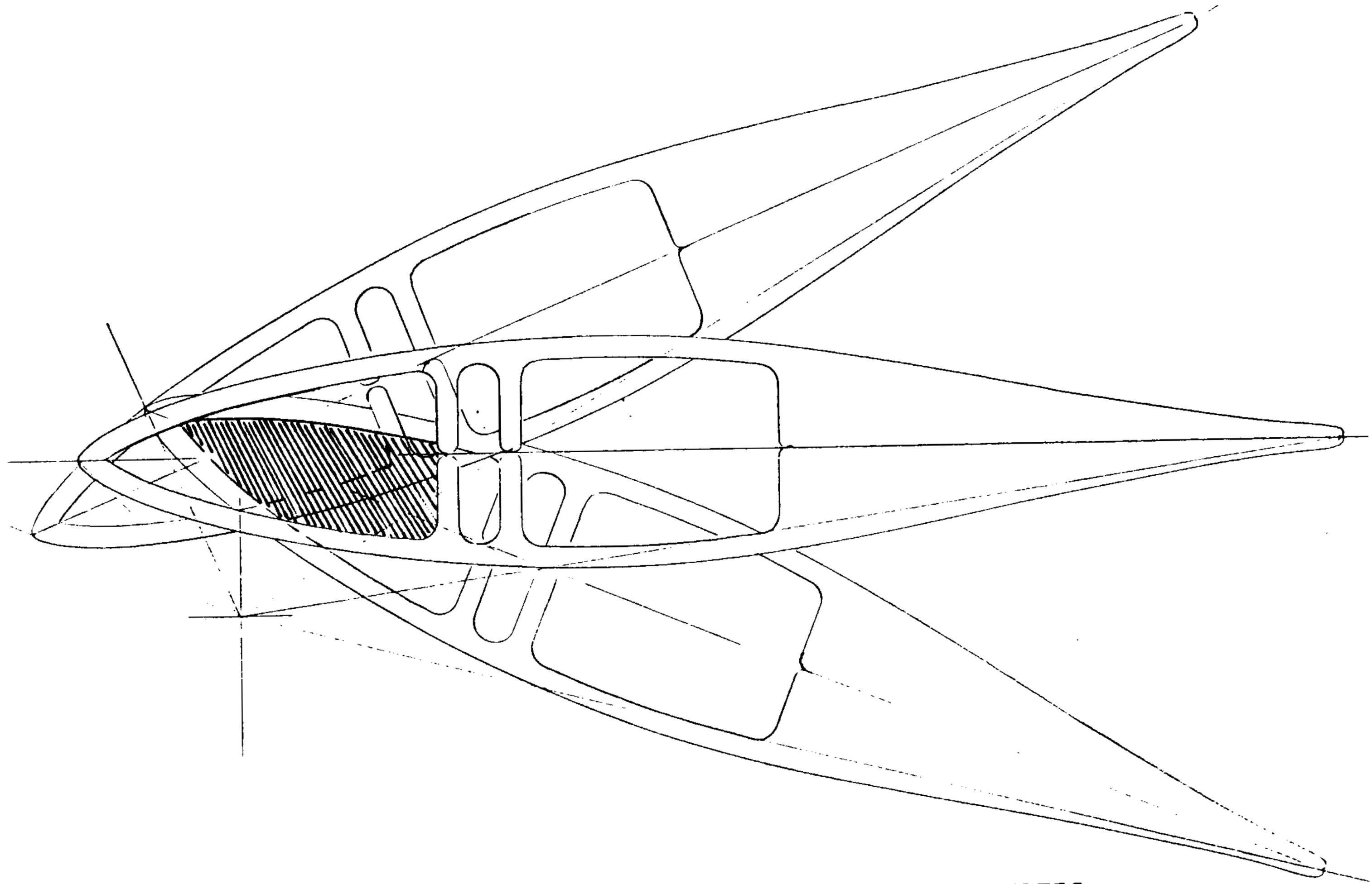


FIGURE 8: AIRFOIL PITCH EXCURSION SCHEMATIC

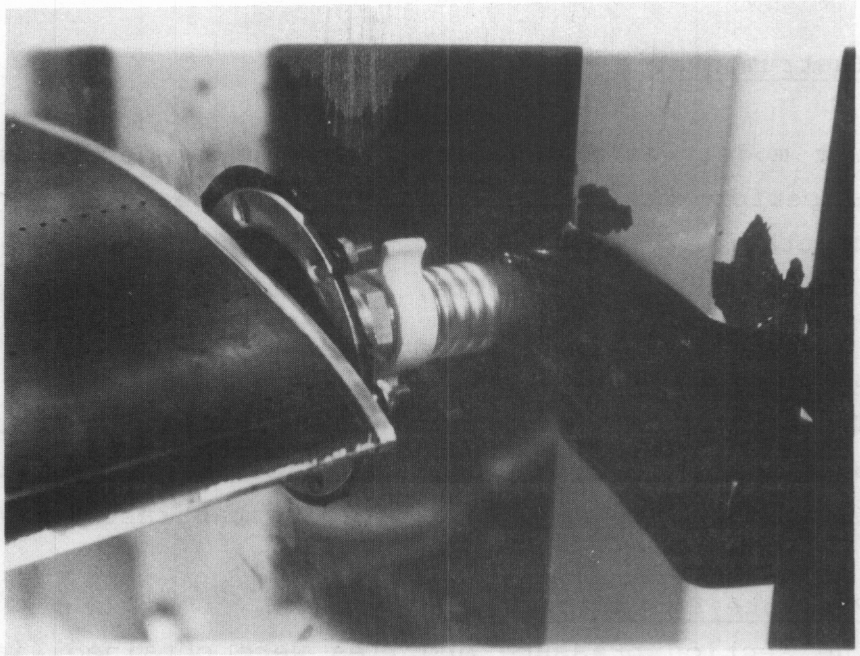


FIGURE 9: DETAIL OF AIR INLET INTERFACE

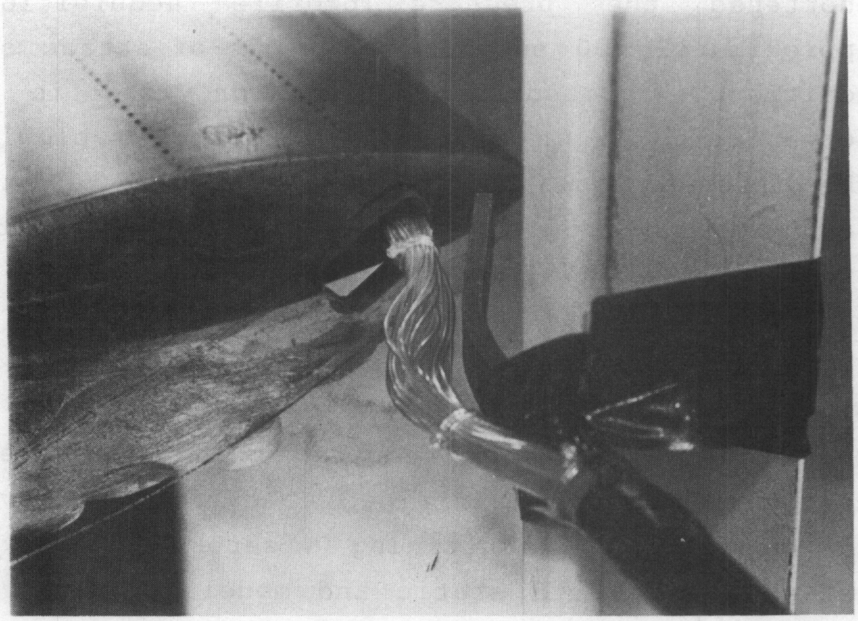


FIGURE 10: DETAIL OF PRESSURE TAP INTERFACE

2.3 Instrumentation

The test model was instrumented to yield a comprehensive picture of its performance. The contract statement of work called for instrumentation provisions that would ultimately provide lift, drag, and moment coefficients, and section pressure profiles.

- Lift, Drag, Moment:
  The force data were obtained directly from the wind-tunnel dynamometer. Their characteristics are itemized in Tables II & III. The raw force data are tabulated in Appendix A.2.

- Pressure Profiles:
  The section pressure profiles were obtained via a series of pressure taps located as shown in Table I. The line of pressure taps is located midway between the model centerline and model tip (¼ span). The pressure data were acquired by three Scanivalves, each with 32 ports (using three valves shortened the pressure profile acquisition time to approximately 30 seconds per angle-of-attack setting). In addition a pressure port was provided in the model's forwardmost plenum to record perforation blowing pressure. The internal pressure port was located at the wing tip farthest away from where the air supply was introduced. All pressure readings were corrected to tunnel bell mouth static.

- Blowing Flow Rates and Pressures:
  The statement of work required that model plenum pressure during blowing be maintained at dynamic head values. This was achieved by maintaining a zero manometer displacement between bell mouth static and model plenum. As the model incremented through the angles of attack, the blowing flow was adjusted to equalize pressures. An attempt was made to measure the mass rate into the model by a pair of

TABLE II

Read-Out Ranges and Sensitivity

	Maximum Value	Minimum Readable Value
Lift	2500 lbs.	1.0 lb.
Drag	250 lbs.	0.1 lb.
Pitching Moment	5000 in-lbs.	1.0 in-lbs.
Yawing Moment	5000 in-lbs.	1.0 in-lbs.
Rolling Moment	5000 in-lbs.	1.0 in-lbs.
Side Force	250 lbs.	0.1 lb.

TABLE III

Balance Ranges & Sensitivity

	Range	Min. Readable Value
Lift		
	25 lbs.	0.25 lbs.
	50 lbs.	0.50 lbs.
	100 lbs.	1.00 lbs.
	250 lbs.	2.50 lbs.
	500 lbs.	5.00 lbs.
	1000 lbs.	10.00 lbs.
	2500 lbs. (Max. value)	25.00 lbs.
Drag and Side Load	2.5 lbs.	0.025 lbs.
	5.0 lbs.	0.050 lbs.
	10.0 lbs.	0.100 lbs.
	25.0 lbs.	0.250 lbs.
	50.0 lbs.	0.500 lbs.
	100.0 lbs.	1.00 lbs.
	250.0 lbs. (Max. value)	2.50 lbs.
Pitch, Yaw and Rolling Moments	50 in-lbs.	0.5 in-lbs.
	100 in-lbs.	1.0 in-lbs
	250 in-lbs.	2.5 in-lbs.
	500 in-lbs.	5.0 in-lbs.
	1000 in-lbs.	10.0 in-lbs.
	2500 in-lbs.	25.0 in-lbs.
	5000 in-lbs. (Max. value)	50.0 in-lbs.

The lift drag and pitch balances have pan weights which may be used to balance out a major portion of the load, thus allowing the remainder to be measured on a more sensitive scale.

Lift	Pan to 625 lbs. by 25 lb. increments
	Pan to 1250 lbs. by 50 lb. increments
Drag	Pan to 62.5 lbs. by 2.5 lb. increments
	Pan to 125.0 lbs. by 5.0 increments.
Pitch	Pan to 1250 in-lbs. by 50 in-lbs. increments.
	Pan to 2500 in-lbs. by 100 in-lb. increments.

"rotometers" and then by an orifice flowmeter. However the clearance gap between the wing tips and the fixed end plate could not be completely sealed. Either the normal spanwise force resulted in problems with dynamometer grounding or the wing-plate gap acted as an ejector. A compromise was reached by installing a "soft" inflated gasket. This arrangement effectively decoupled the model from the end plates but it did allow some additional unquantifiable inflow into the model.

As a result the blowing mass rate is determined by using flow conditions existing at the perforations. During tests with blowing, the internal pressure in the model plenum is known as well as the pressure profile on the outside surface. This pressure difference together with the perforation geometry yield the mass rate.

3.0 TEST PROCEDURE

3.1 Test Conditions

For all tests the Reynolds number was held at a nominal 1.5M. This requirement dictated a tunnel q = 70 psf. The statement of work specified model configurations that involved five test runs. These are

(a) All perforations sealed (no blowing).
(b) First row open (top & bottom) (no blowing).
(c) First row open (top & bottom) (blowing).
(d) Second row open (top & bottom) (no blowing).
(e) Second row open (top & bottom (blowing).

The actual number of test runs was expanded to a total of 32. In addition to calibration runs, tests were conducted to assess the sensitivity of the system to various configurational changes. The test program concluded with a flow visualization run using fluorescing dyes. The specific details of each configuration are delineated in Table IV. Of these test runs 12, 15, 20, 22, and 31 are with perforation blowing. Runs 8 and 29 are the "baseline" airfoil with no blowing and all perforations taped.

3.2 Test Sequence

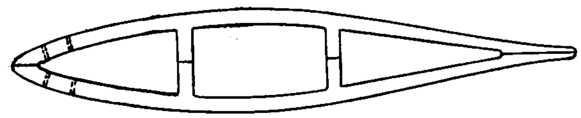
The data acquisition followed a systematic procedure. The sequence is as follows:

(a) A specific model configuration was established (appropriate perforations were masked).
(b) The tunnel was brought up to the test Reynolds number (given by q = 70 psf).
(c) An angle of attack of -2° was set. (The tunnel dynamometer did not allow the model to be pitched to 24°, only 22° was possible).

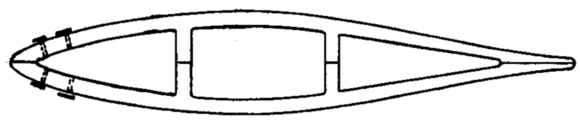
TABLE IV

TEST RUN DESCRIPTION

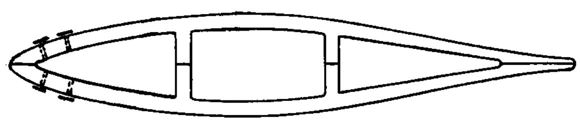
Run 7. First and second rows open on top and bottom, no blowing, inlet flange open.



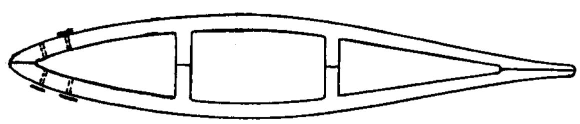
Run 8. First and second rows taped, no blowing, inlet flange open.



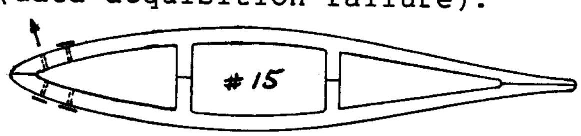
Run 9. First and second rows taped, no blowing, inlet flange open, tip foam seals removed.



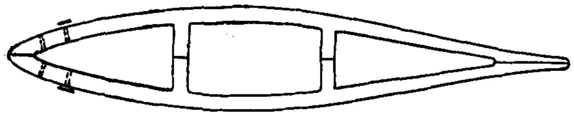
Run 11. First row top open, no blowing.



Run 12. First row top open, blowing (aborted seal failure).
Run 14. Repeat 11.
Run 15. Repeat 12.
Run 16. Abort (data acquisition failure).

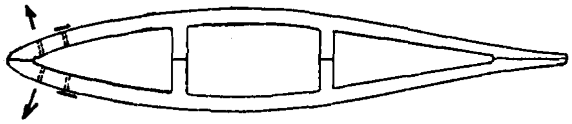


Run 17. First row top and bottom open, no blowing, inlet flange open.

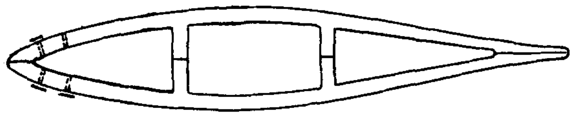


Run 18. First row top and bottom open, no blowing, inlet flange closed (taped).

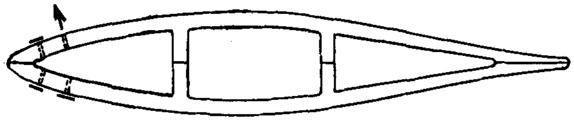
Run 20. First row top and bottom open, blowing.



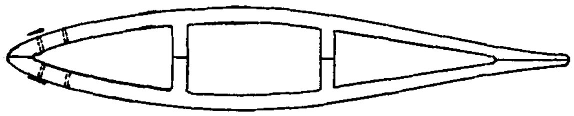
Run 21. Second row top open, no blowing, inlet flange open.



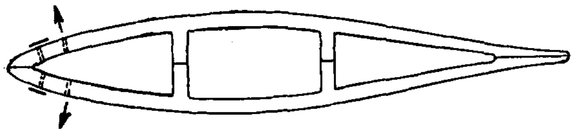
Run 22. Second row top open, blowing.



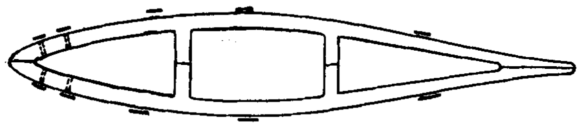
Run 23. Second row top and bottom open, no blowing, inlet flange open.



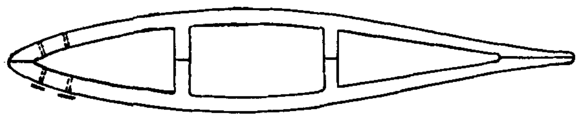
Run 24. Second row top and bottom open, blowing.



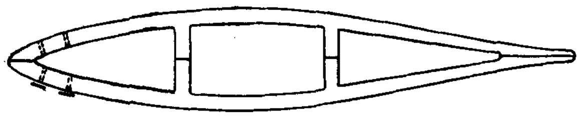
Run 25. Same configuration as 7 (check runs).
Run 28. Holes from previous 1985 tests are taped externally, first and second rows top and bottom are open, no blowing (same as 7).
Run 29. All holes are taped - clean airfoil.



Run 30. Same as 28 except first and second rows top are open, no blowing inlet flange open.



Run 31. First row top is open, blowing (check run to 12 and 15).
Run 32. Flow visualization run at 0, 4, 8, 12, 16 degrees (no blowing).



(d) If the test run involved perforation blowing, the air supply was turned open until model internal pressure equalled tunnel bell mouth static pressure.

(e) After conditions were stabilized (approximately 30 seconds) the force and pressure data were recorded.

(f) The angle of attack was then incremented by 2° and the cycle repeated.

A "typical" test run, including model configuration change, required on the average 1¼ hours.

3.3 Data Reduction

At the end of each run the uncorrected coefficients were plotted and evaluated as to reasonableness and trends. The raw force data are tabulated in Appendix A.2.

After all the tests were completed the raw data were corrected before final plotting and tabulations. A total of four corrections were made to the raw force data:

- Balance interaction correction.
- Weight tare.
- Blockage correction of q as a result of wing and wake (no blockage correction was applied due to stanchions and end plates).
- Fork drag tare. (The supporting fork, pitch horn, and mounting blocks were run alone and the drag of 6.07 lbs subtracted from total drag.)

The pressure profiles are corrected to the extent that the pressure coefficient is referenced to a corrected q.

4.0 DISCUSSION

The following discussion is structured into three topics. The first part deals with the model performance with and without blowing - the fundamental question of this test. The second section focuses on a unique phenomenon - crosstalk - which, although not unexpected, will nevertheless have to be considered in the design of pump spoiling mechanisms. The third element of this discussion is devoted to a description of a number of observations and unique behaviors of the model.

A number of general points can be made for the overall test program.

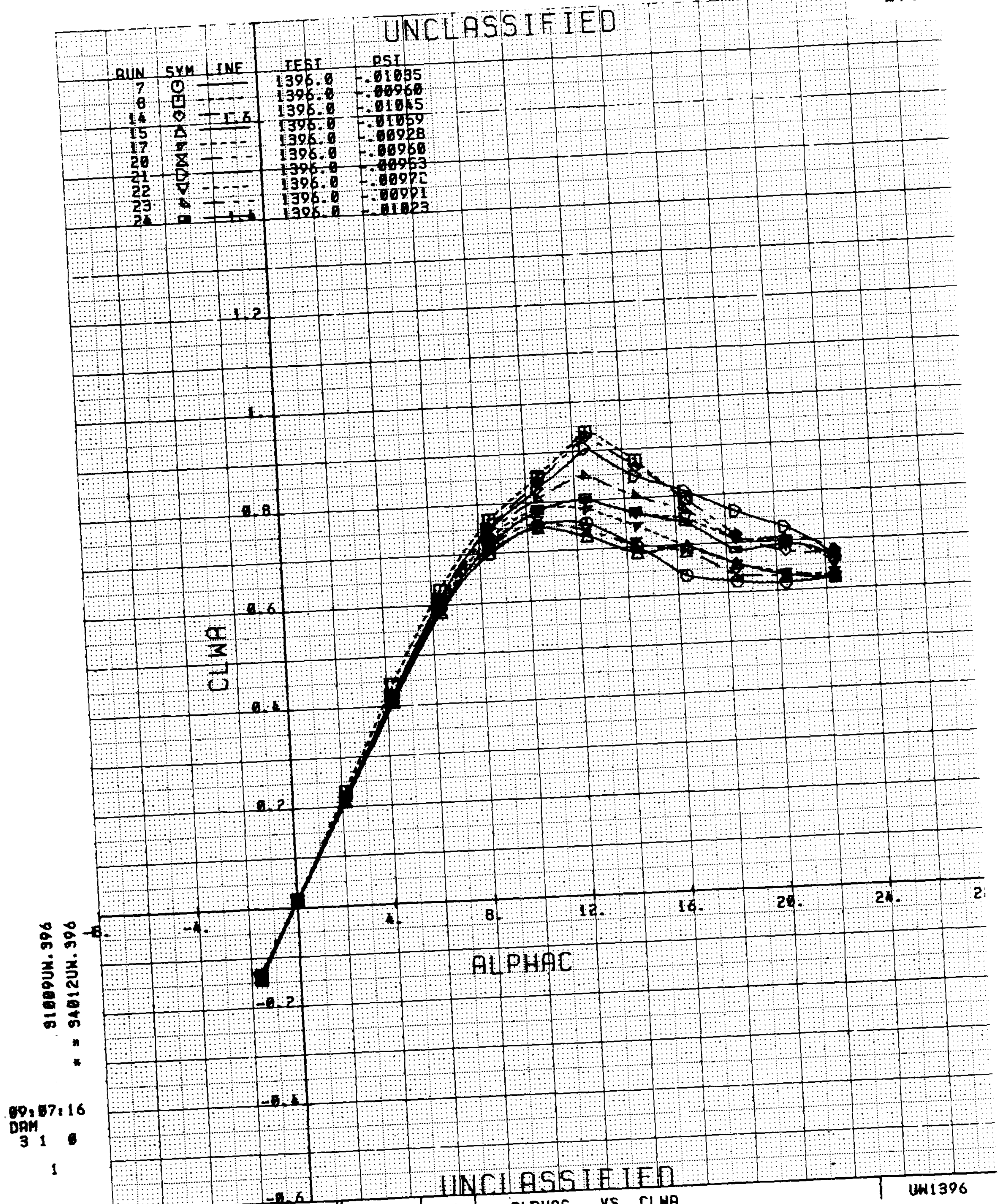
- In all tests the model was very well behaved up to approximately 12°. Past 14°, apparently with the onset of stall, the model began to exhibit roll and yaw oscillations. They were irregular and increased in severity as the angle of attack increased. However at no time were the motions so severe as to cause the pressure tap bundle to contact the end plates nor the air supply aperture to vent outside the section profile.

- In the planning for this test series and from the experience with the 1985 tests it was realized that the drag coefficient would require close scrutiny. The main source of concern was the unknown drag of the supporting pitch fork and the control horn and the effect of their presence on the drag of the model. Typically uncorrected zero lift drag coefficients were approximately .0275. It was intended to obtain a "clean" model drag coefficient and then correct the test runs appropriately. The model was to have been suspended at the tips and instrumented for drag by forceblocks in the end plates. The University of Washington support forks would then be removed and the model tested at 0° angle of attack.

Although this approach was initially approved by the University of Washington wind tunnel director, it was subsequently determined that the scheme would not have a sufficient safety margin and hence was not attempted. An alternate approach was used. In the last run (33) the model was removed from the support forks and a drag value for the forks and model mounting blocks was obtained alone at a tunnel q of 70 psf. This drag was then subtracted from the total system drag as a drag correction. Together with the standard corrections for q and blockage effects, this brings the corrected zero lift drag coefficient to approximately .0175. Unfortunately the interference effect of the mounting forks and support blocks on the drag of the model still remains unknown. It appears reasonable to assume that the difference between the corrected values of .0175 and an expected value of approximately .009 is due to the interference of the mounting system.

- The method of air conveyance to the model involved blowing the supply air from a fixed end plate across a narrow gap to the model wing tip. This arrangement tended to act like an ejector and to an unknown degree may have impacted the external flow field in the tip region. It was also observed that the ejector action caused depressed pressures in the immediately adjacent zone of the model plenum. This effect could be minimized by increasing the model-to-end-plate clearance gap. (The entrainment action takes place in the clearance gap and not in the model plenum.) A clearance gap balance was struck such that during blowing runs, no perforations exhibited suction.

For the purposes of this discussion the most illustrative runs were selected and plotted. The complete raw and reduced data are found in Appendices 2 and 3. A typical range of results is illustrated in Figures 11, 12, and 13. The maximum lift coefficient of .94 occurs at approximately 12° for the case of a



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ALPHAC VS. CLWA

FIGURE 11:

1050 AIRFOIL

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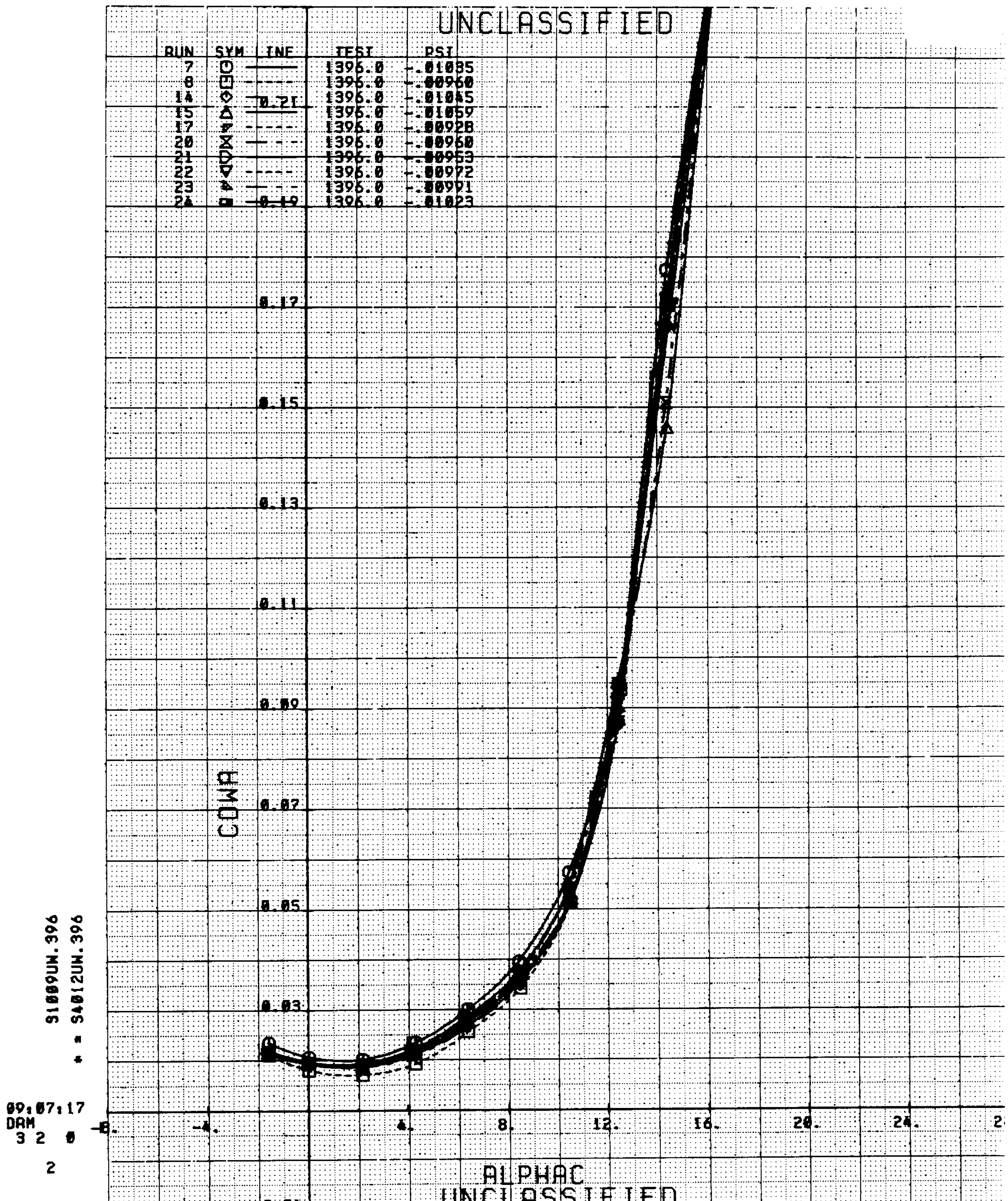

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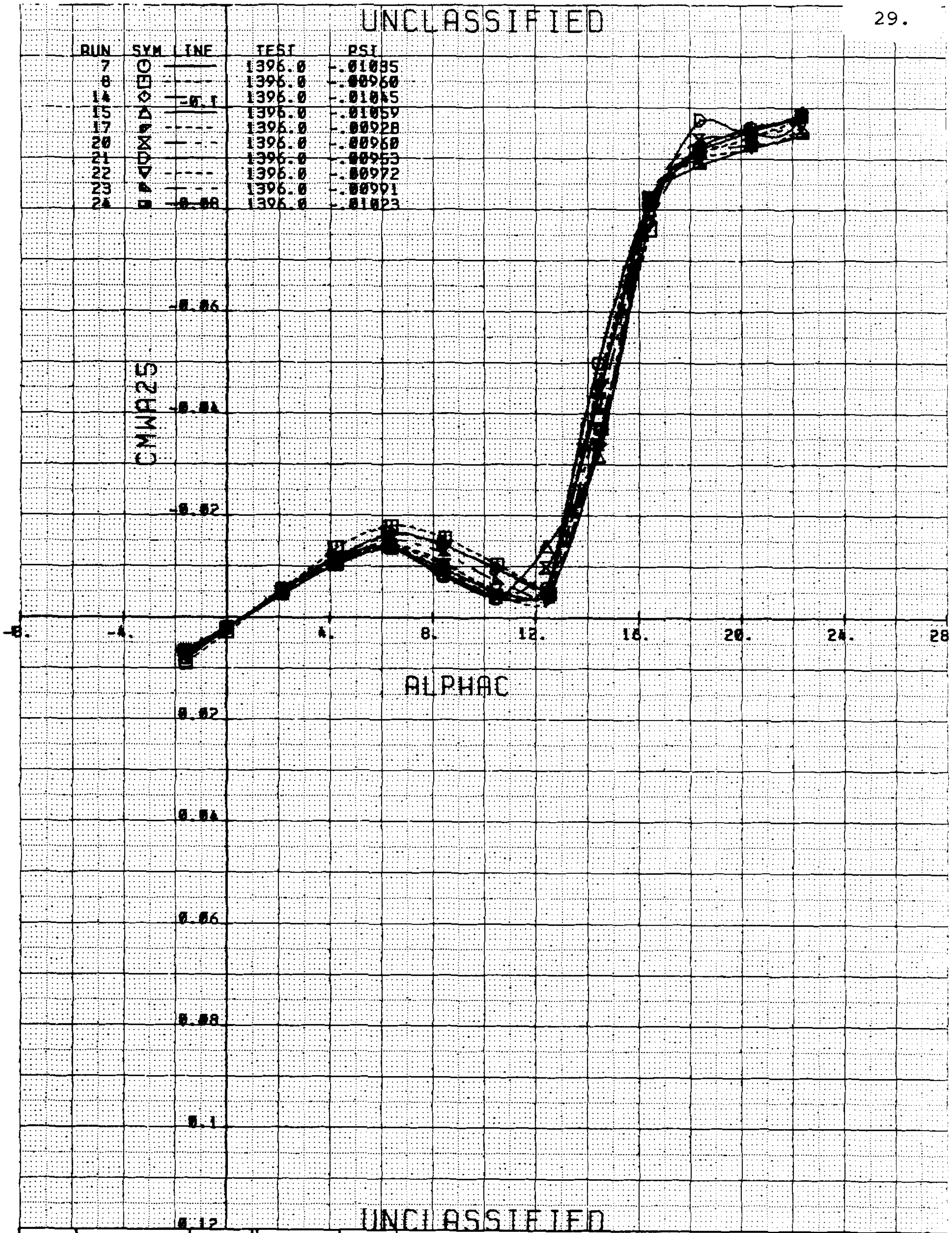
FIGURE 12:



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clean or no blowing configuration. With blowing or with top and bottom perforations uncovered the maximum lift coefficient is approximately .75 and occurs at approximately 10°. This represents a lift coefficient decrease of approximately 20%. Various configurations discussed in the following sections fall in between.

4.1 Blowing Effect

The comments on the blowing effect are divided into two subsections: impact of first row perforations and impact of second row perforations. The characteristic runs illustrating first row operation are run 8 as a reference and run 14 for perforations open, top only, but no blowing. Run 15 illustrates the changes in the lift coefficient with blowing. These trends are depicted in Figures 14, 15, and 16. Run 20 is for the model configuration in which there is first row blowing at top and bottom.

It is clear that the upper surface behavior controls the lift coefficient. The model performance with the second row of perforations involved is illustrated in Figures 17, 18, and 19. Here again run 8 is used as a reference. With the top second row open and no blowing (run 21) there appears to be an approximate 4% decrease in the maximum lift coefficient. With blowing (run 22) the maximum "spoiled" lift coefficient is .8. Interestingly, this is higher than the .75 maximum lift coefficient for the first row blowing case (run 15). If the second row top and bottom are left open but there is no blowing (run 23), then the maximum lift coefficient falls between the clean airfoil (run 8) and the blown "spoiled" case (run 23). With blowing, the maximum lift coefficient decays to .8. For the second row the lift coefficient control range is approximately 10%.

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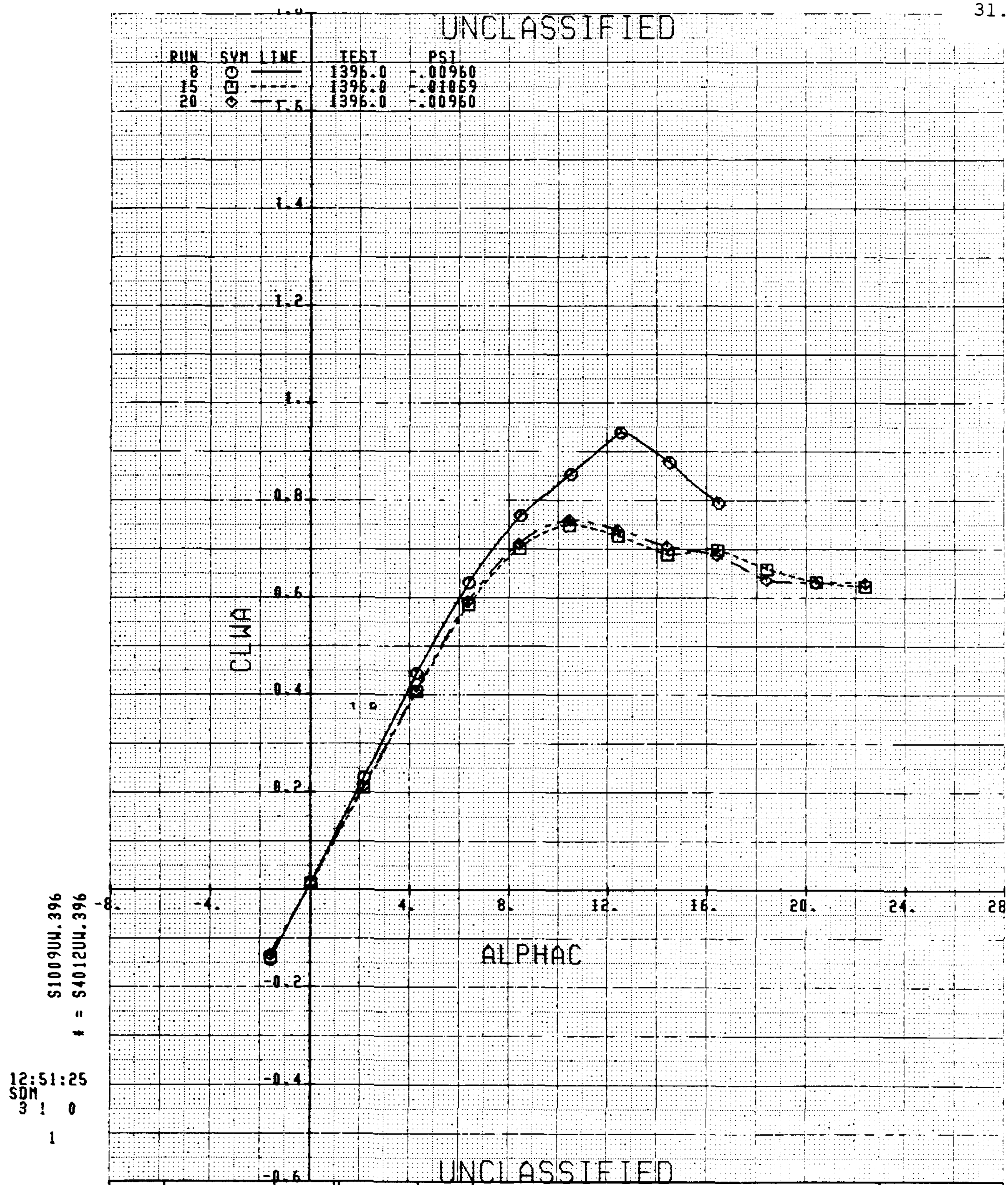

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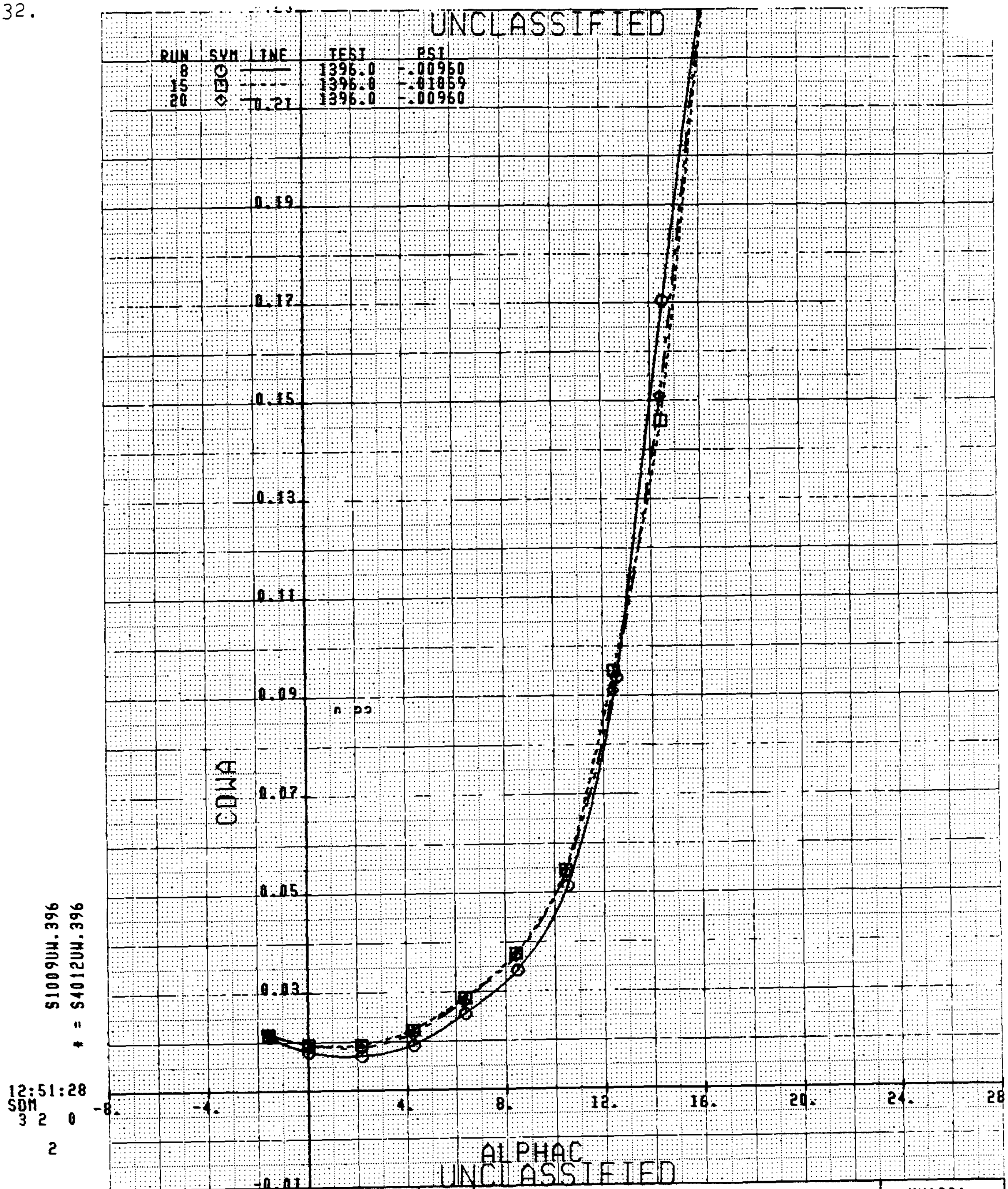

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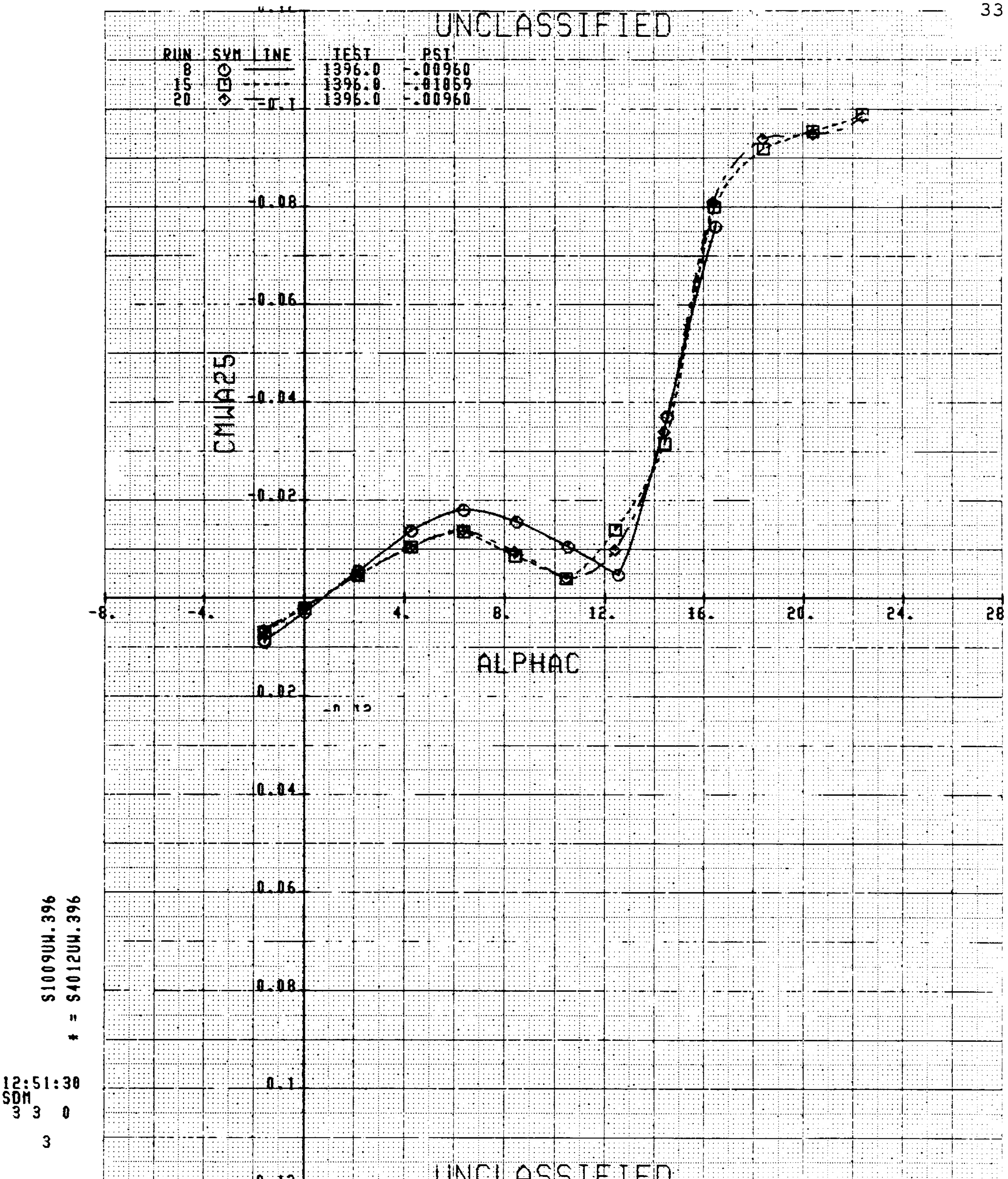

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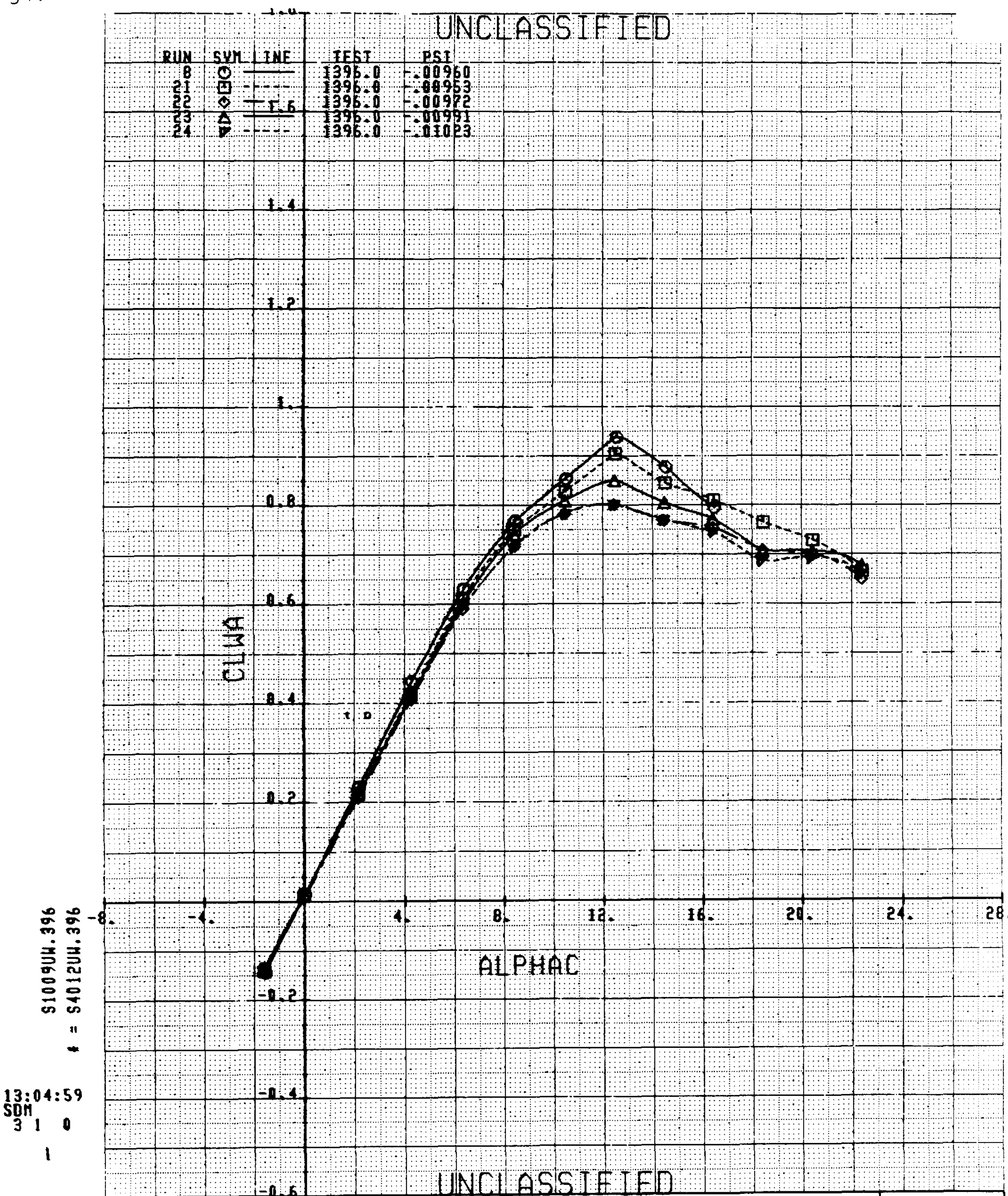
FIGURE 16:



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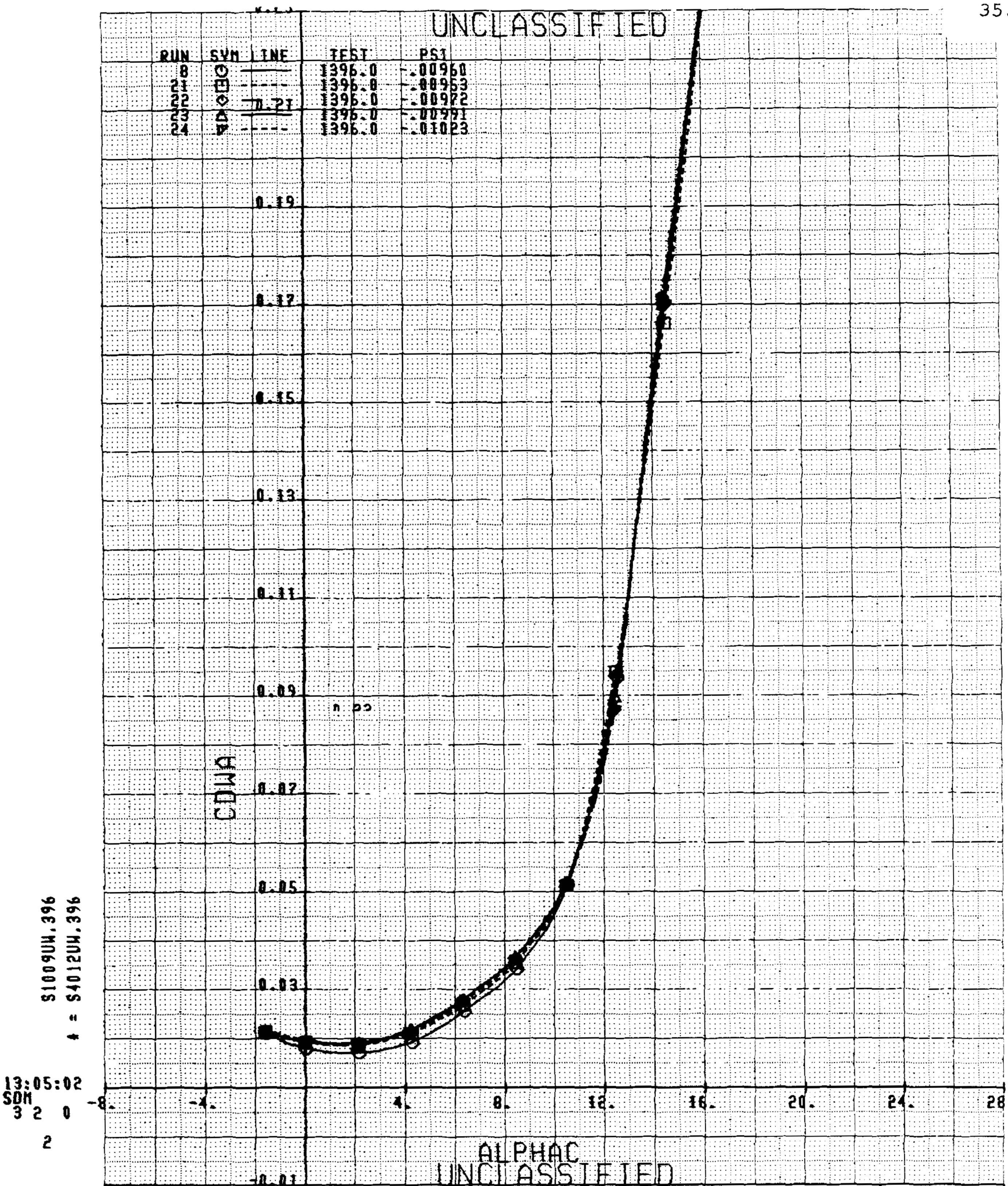

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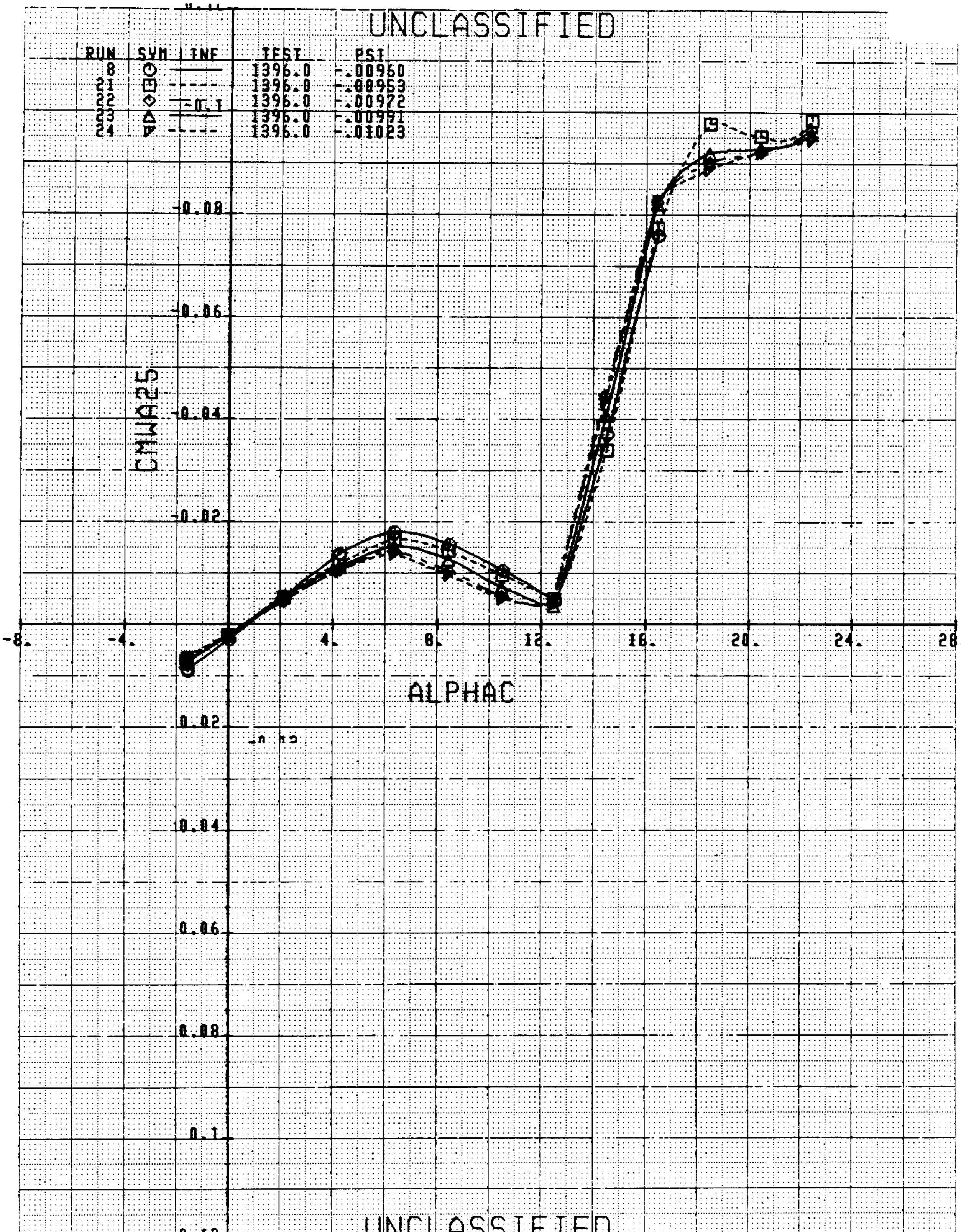

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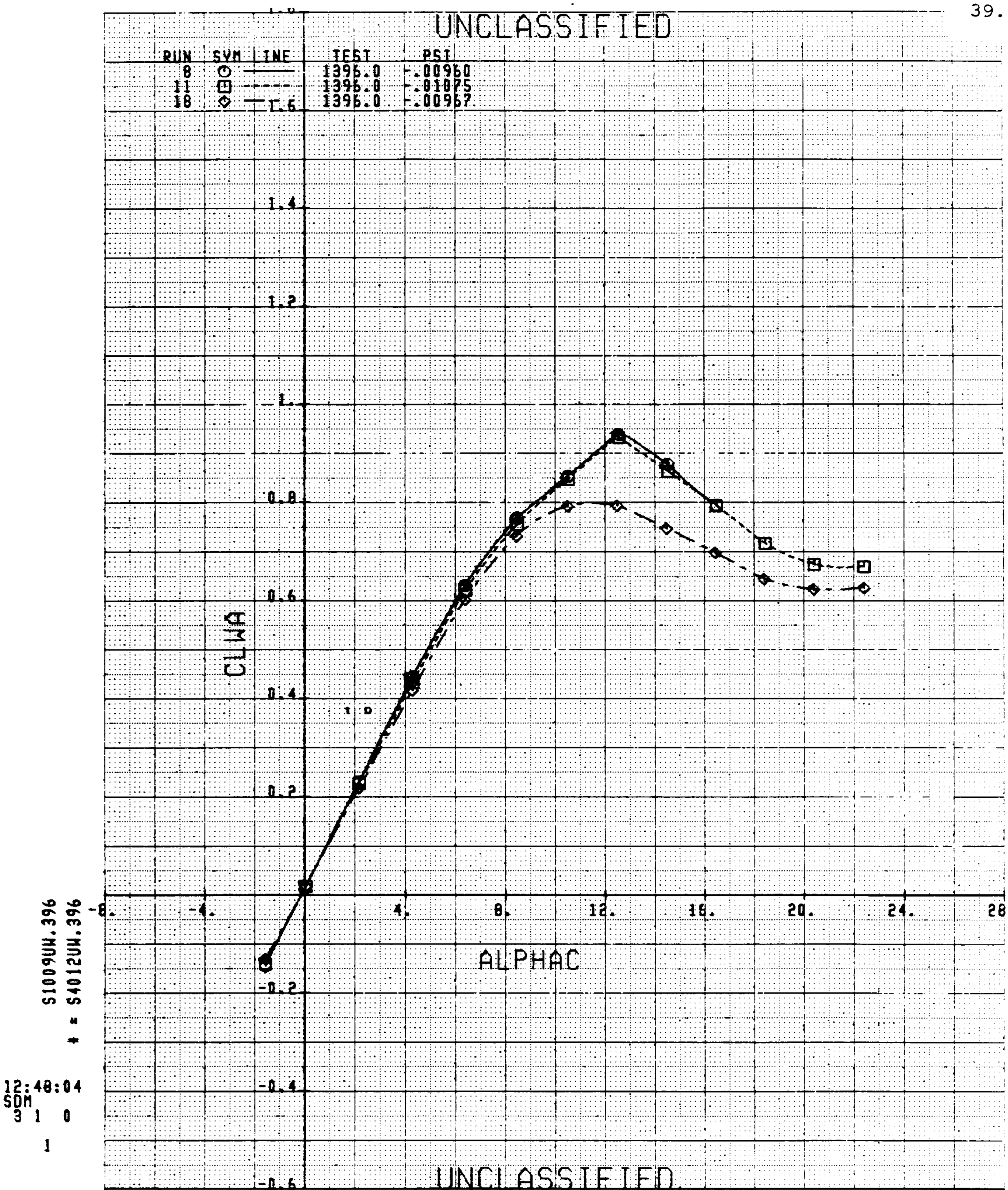
It can be reasonably concluded that:

- The first row perforations are more effective in controlling the maximum lift coefficient.
- The greater change in lift coefficient with and without blowing is achieved with the first row perforations.
- The suction side perforations are dominant in controlling the lift coefficient.

4.2 Crosstalk

In the earlier 1985 tests (Figure 1) the spoiling effect was achieved only when the perforations were made at the 7.5% chord location. The only tests made at the time were with perforations on the suction side. The question remained as to the performance of the model with perforations at the same chord station but on both top and bottom surfaces. To resolve this test runs were made to compare the effect of perforations open top only and open at top <u>and</u> bottom. Figures 20, 21, and 22 are typical of the results. Again run 8 is used as a reference.

With the first row perforations open only on the upper surface (run 11) the performance is almost identical to that of the reference clear airfoil (run 8). If the corresponding bottom row of perforations is opened (runs 17 and 18) then the maximum lift coefficient decreases by approximately 15%. It is evident that when both rows (top and bottom) are open - even without blowing - a form of crosstalk occurs. It appears that the bottom (positive pressure side) perforations feed the model plenum, which in turn feeds the suction side perforations and establishes a "passive" spoiling. The same effect was evident with the second rows of perforations at 7.5% chord but to a lesser degree.



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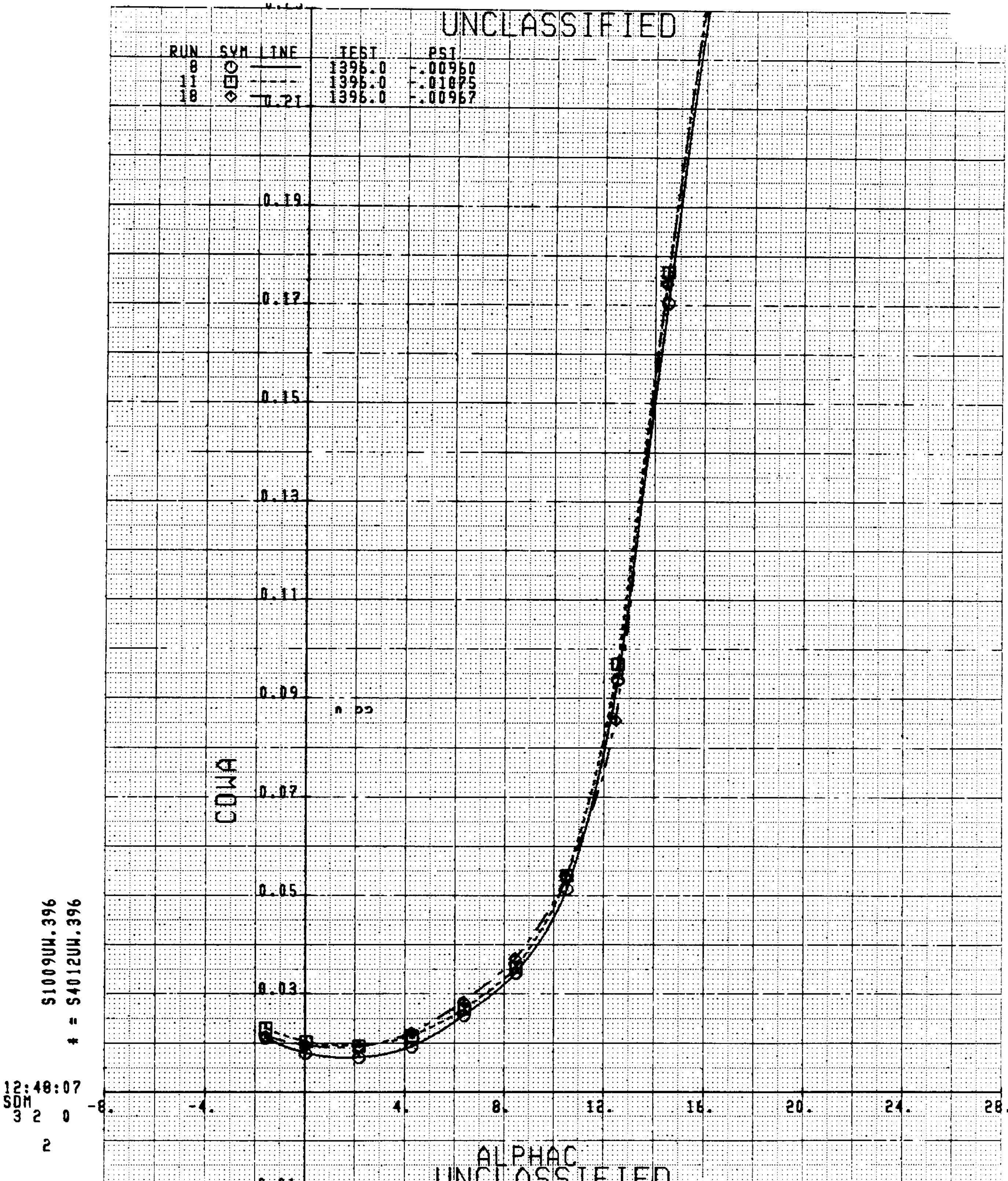

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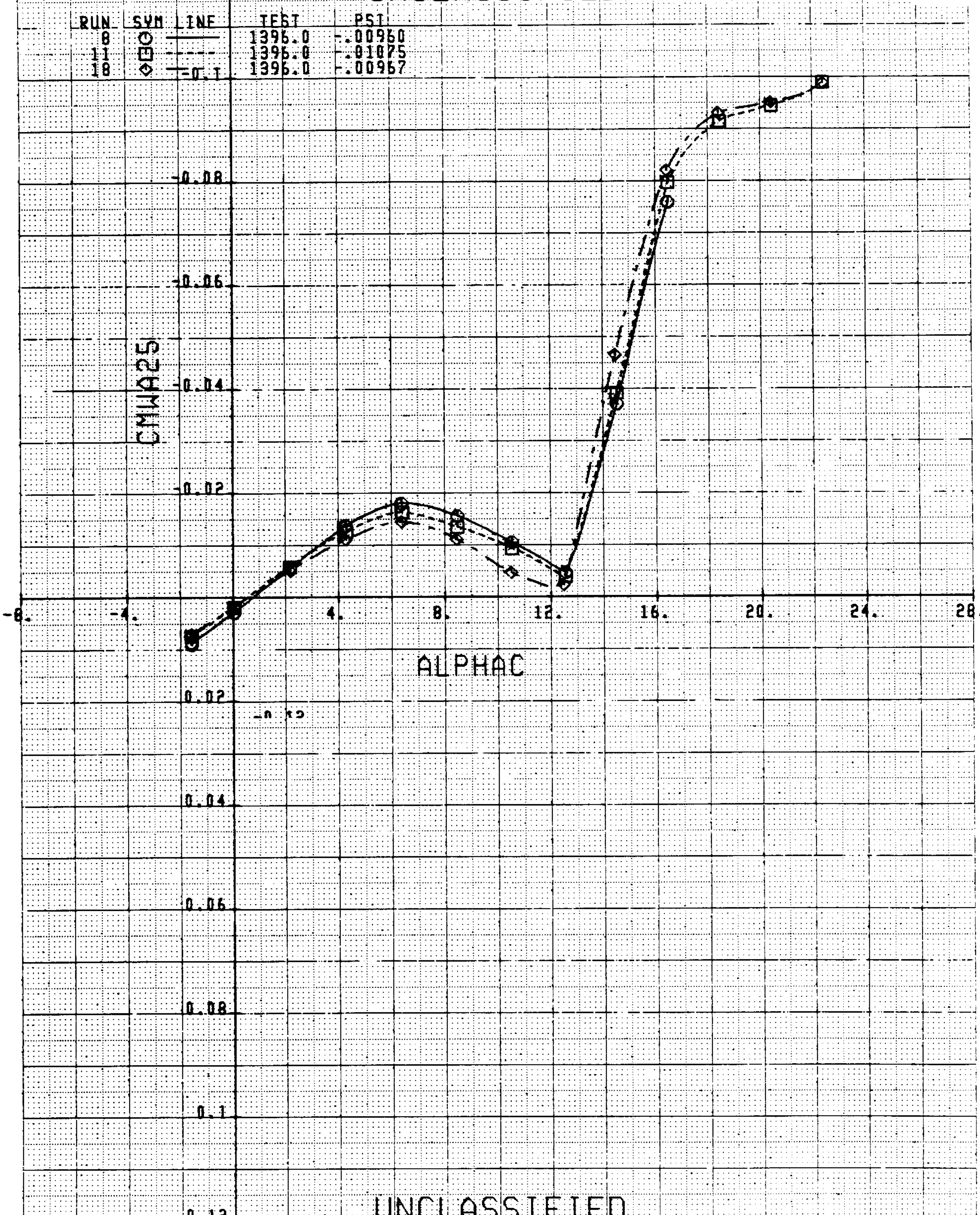

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4.3 Exploratory Tests

Several test runs were made to explore the impact and sensitivities of the model to the unique mounting and air supply configuration. Figures 23, 24, and 25 illustrate the effect of internal plenum sealing on the model performance. Run numbers 7 and 8 bracket the model performance. It was thought that with the wing tip inlet flange being open (without blowing) enough air would be admitted to the plenum to cause spoiling. Runs 17 and 18 compare the performance with the inlet flange open and taped, respectively. There appears to be a minimal change in the lift coefficient.

A purely inquisitive test run was made to evaluate a configuration in which both rows of perforations are open on one side only (suction side). The results are set in perspective in Figures 26, 27, and 28. For this special configuration there is a lift coefficient decrease of approximately 6%. It is postulated that a quasi-spoiling occurs. The chord region, where the two rows of perforations are located, is in a zone of very steep pressure gradients. It appears that the second row of perforations is at a higher pressure relative to the first row and supplies spoiling air to the model plenum, which in turn feeds the first row - ultimately to cause a degree of spoiling.

The last test run (32) was an attempt to visualize the flow behavior on the model. To this end the model was coated with an emulsion of fluorescing agent and water soluable carrier. The model was operated at 0, 4, 8, 12, and 16°, and photographs were taken under a UV light. The results are depicted in Figure 29. Interestingly the perforations from the 1985 tests (which were taped on the inside) formed discreet supply wells for the dye. It is evident that through an 8° angle of attack the flow is relatively well behaved. At 12° evidence of reverse flow appears and at 16° the model has pronounced reverse flow zones.

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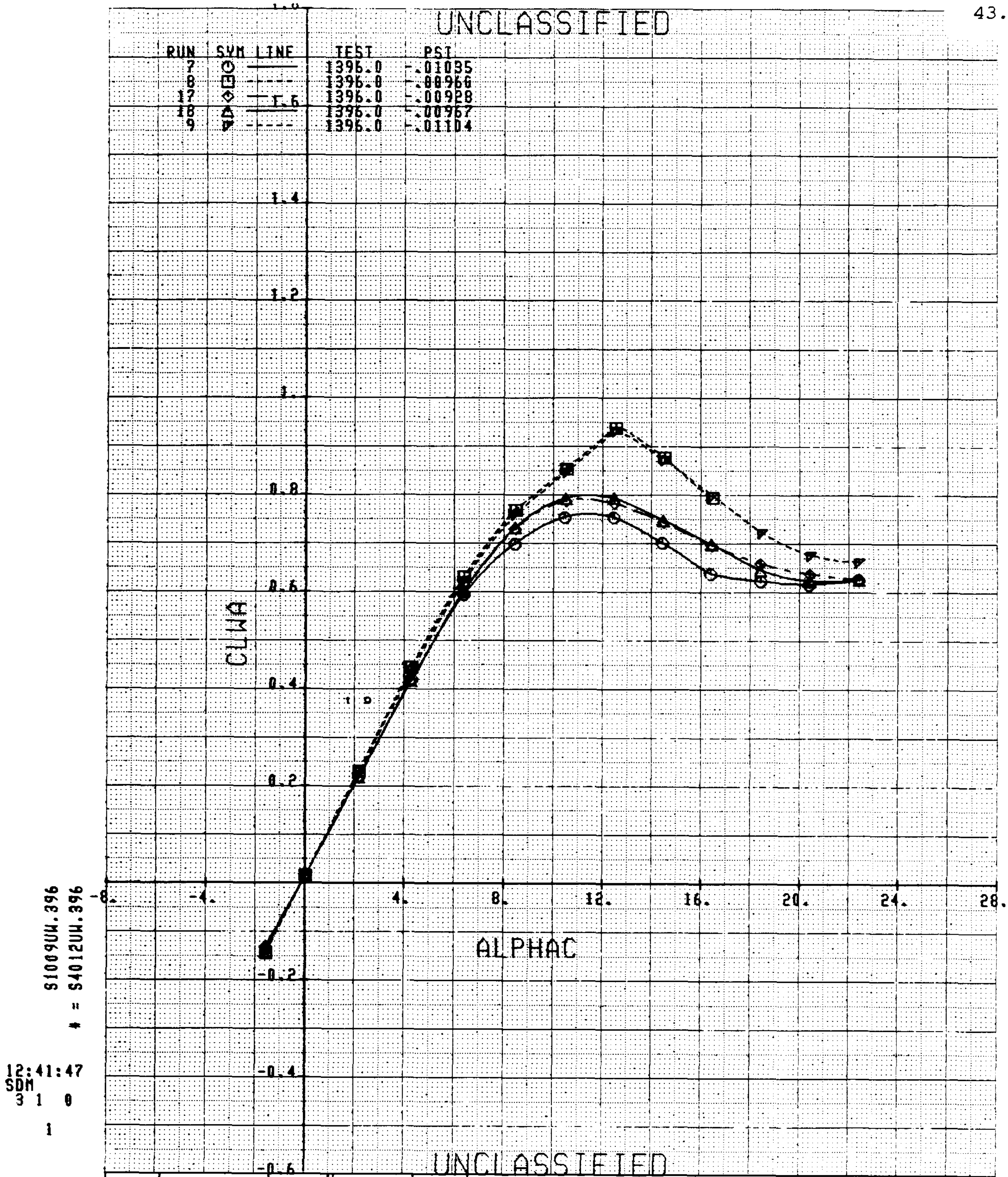

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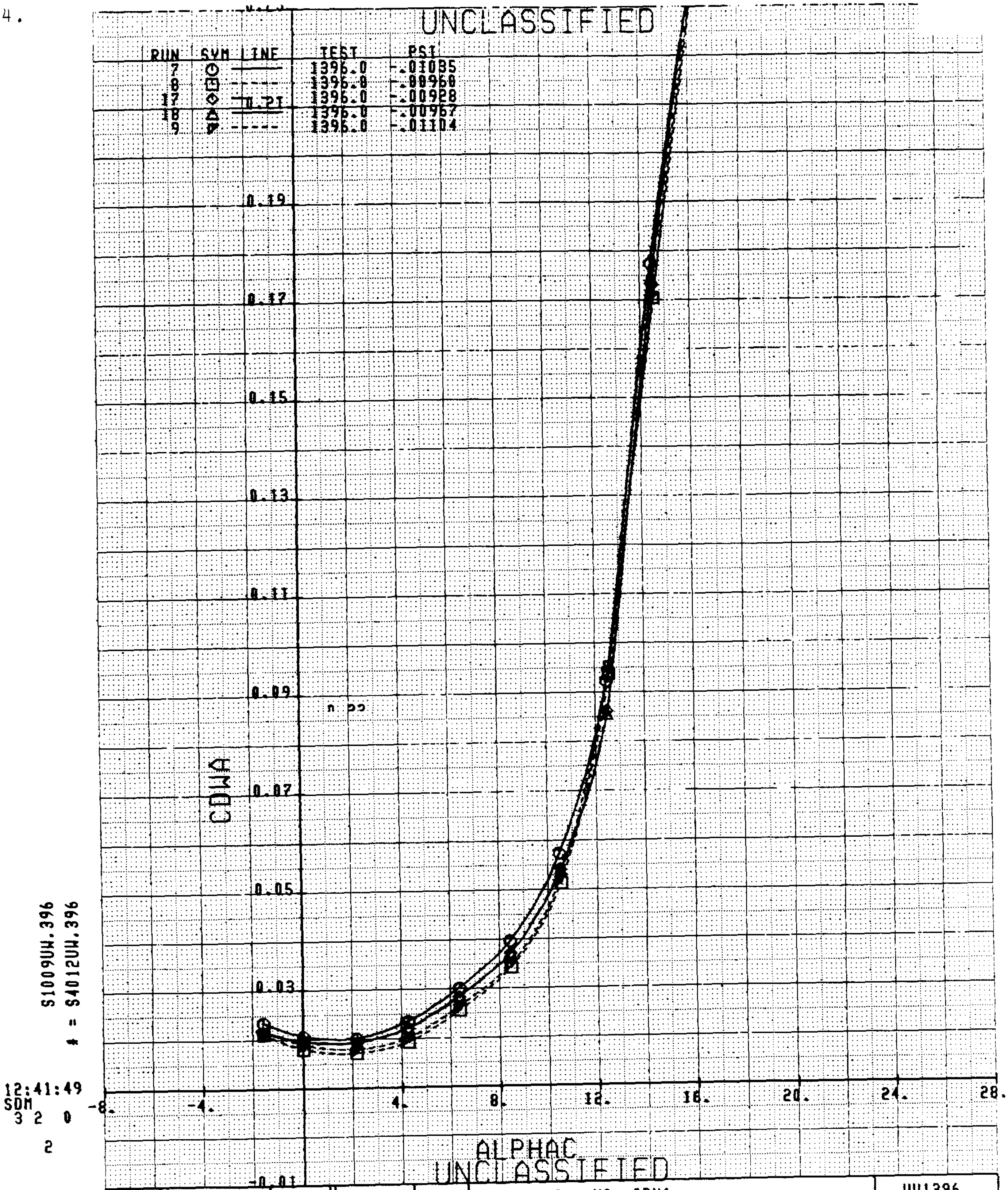

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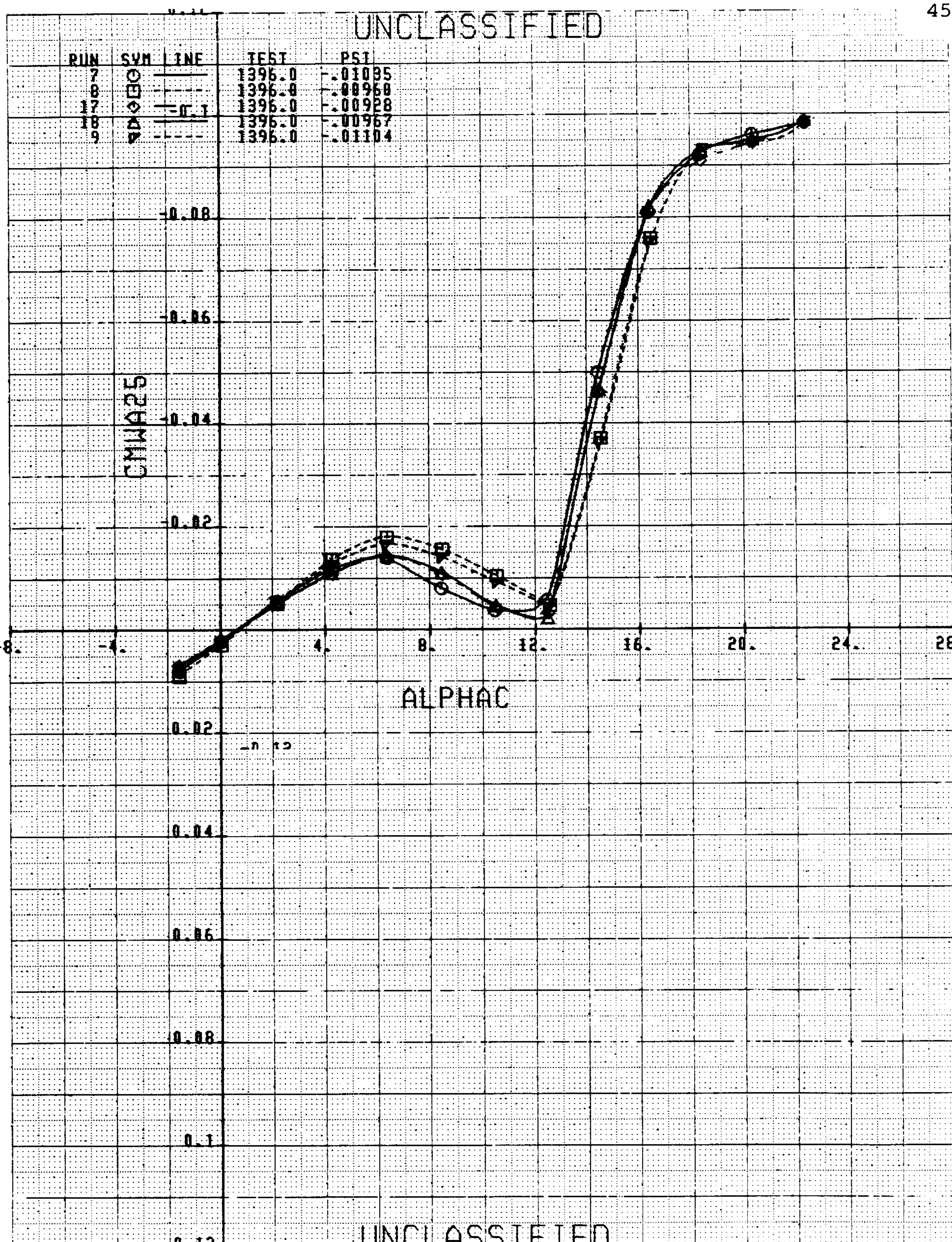

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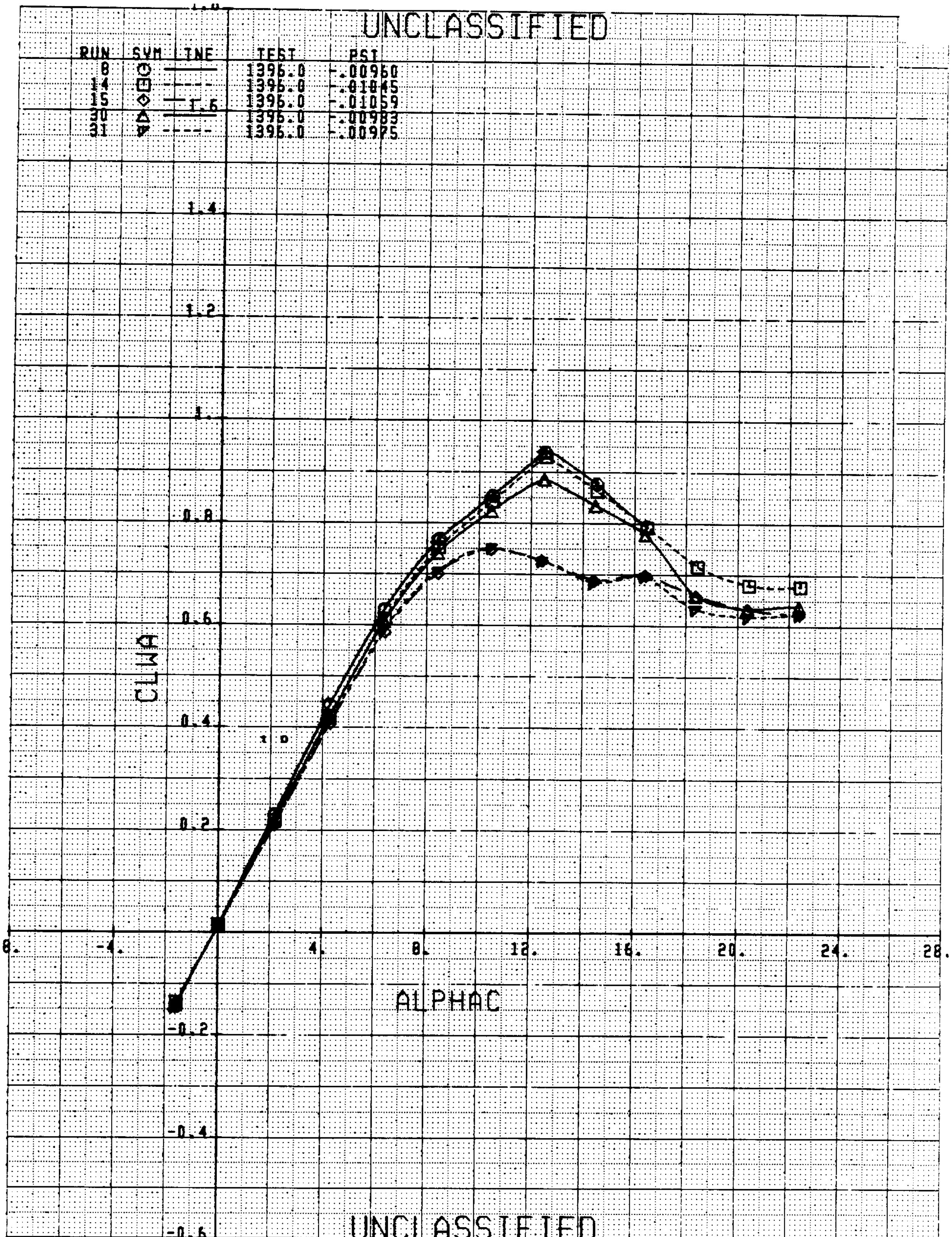

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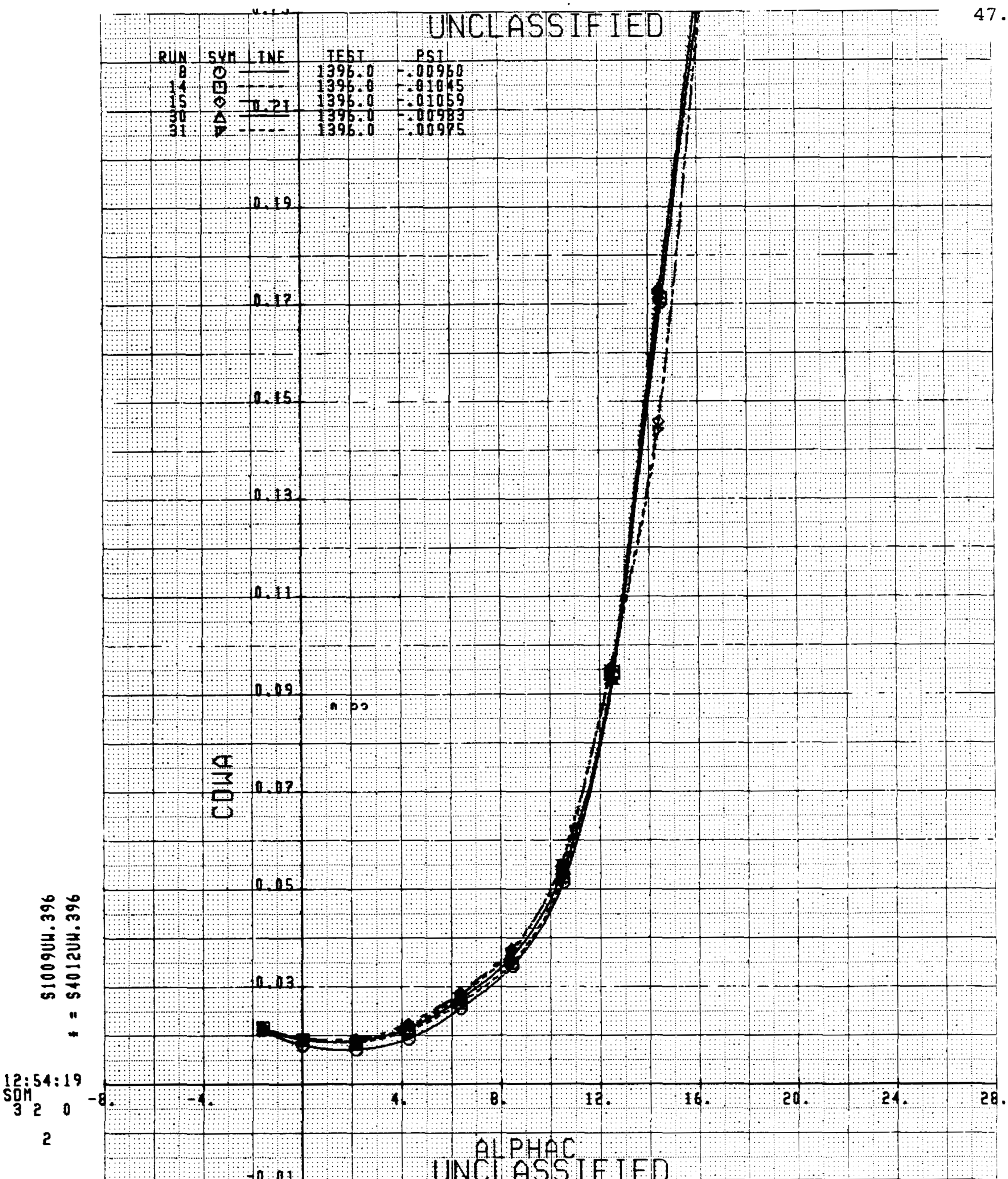

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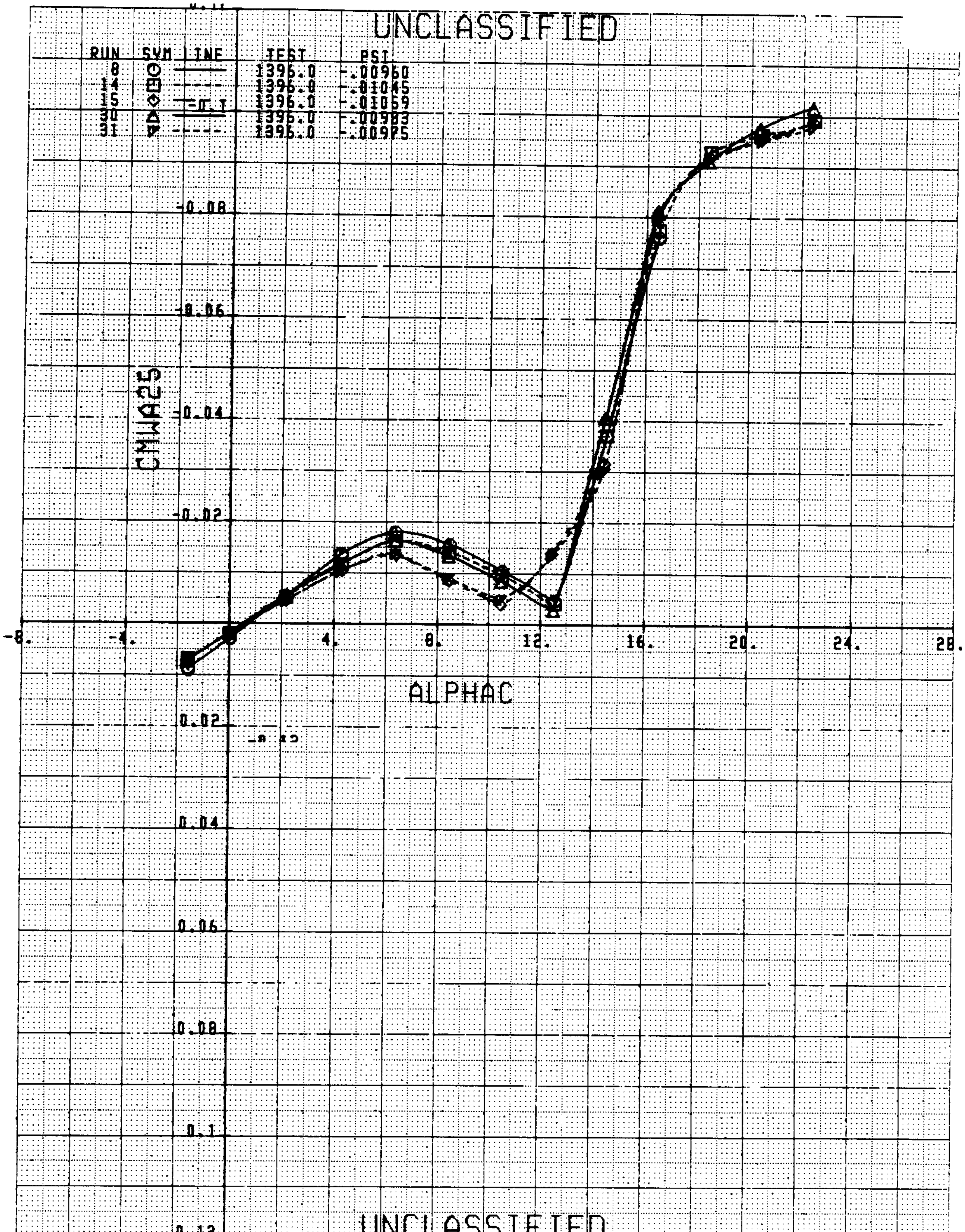
FIGURE 27:



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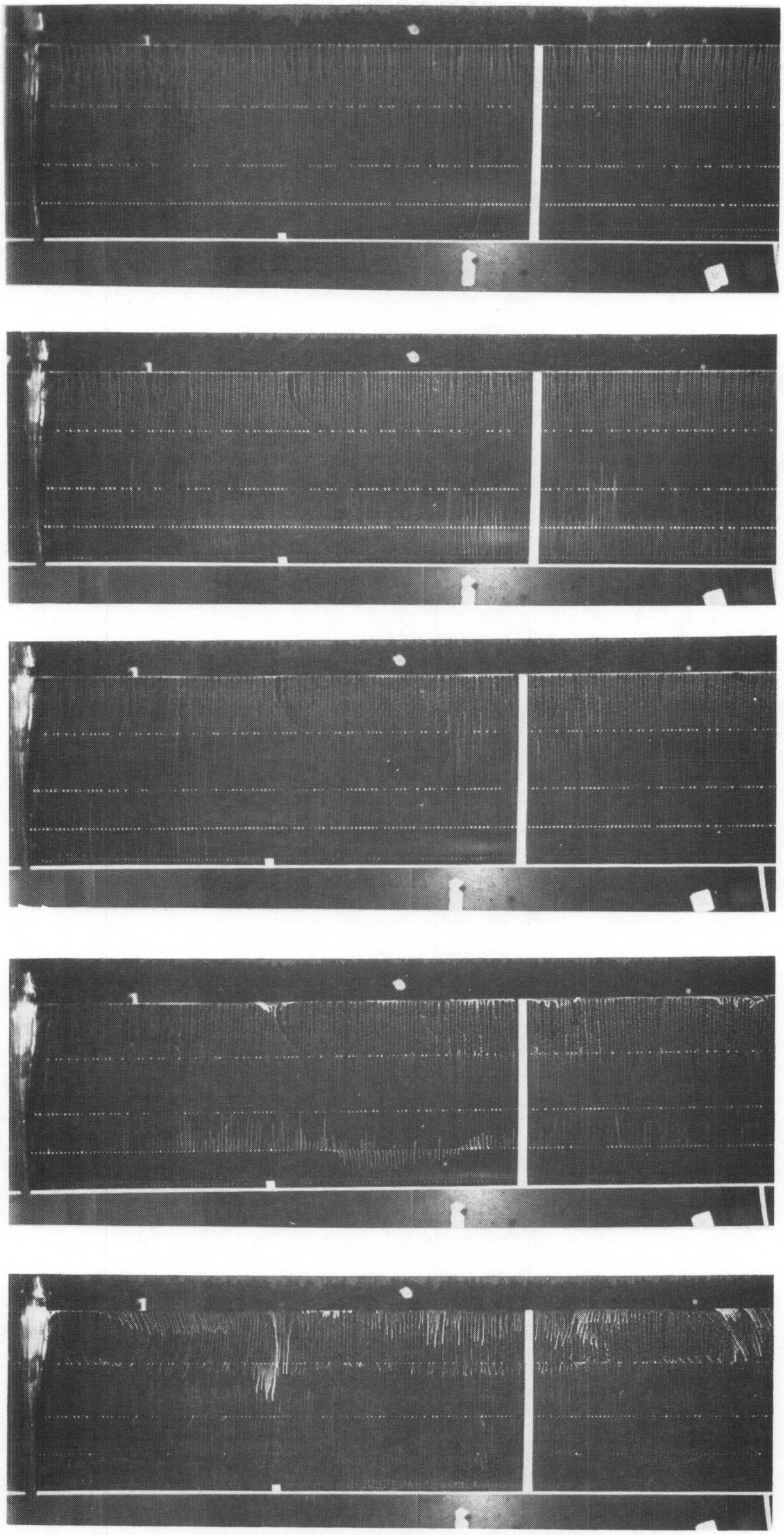

0°

4°

8°

12°

16°

FIGURE 29: FLOW VISUALIZATION OF SEPARATION

APPENDIX A.1:

CONTRACT STATEMENT OF WORK

Statement of Work

The tasks described below are intended to result in establishment of a firm data base to be used in the design of a centrifugally pumped spoiling vertical axis wind turbine power control system.

1. SNL will provide a rectangular planform wind tunnel model of the SAND 0018/50 airfoil section for use under the contract. This model has a 305 mm chord and an aspect ratio of 9. It was fabricated by joining two identical half blade extrusions (Attachment A) along their common x-axes. The model must be modified by the contractor in the following ways:

   a) 1.60 mm diameter x 6.35 mm perforations will be drilled full span on both upper and lower surfaces of the airfoil model at 11.5 mm and 23 mm chordwise locations (measured from the leading edge).

   b) Means will be provided for measuring midspan pressure distributions on both sides of the model at a minimum of 29 separate locations. These chordwise locations (expressed in % of chord) are ± 0, 2.5, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, 50.0, 70.0, 80.0, and 95.0. Means for checking flow two dimensionality (via pressure measurement) will be provided on upper and lower surfaces at the 25.0 and 70.0% chord locations at ± one chord distances either side of center span.

   c) Means will be provided for pressurizing the forwardmost cell of the model. The maximum pressure to be maintained will be 75 psf.

   d) Means will be provided to supply compressed air to the model's forwardmost internal cell. It is estimated that the volumetric flow rate capability of the compressed air supply system need not exceed 3 ft^3/sec. This supply system will provide the air which is to be exhausted through the a) above perforations.

2. The model will be statically wind tunnel tested to obtain the following quantities:

   a) Sectional lift, drag, and moment coefficients and center of pressure locations.
   b) Chordwise pressure distributions.

   Measurements will be made for angles-of-attack between 0 and 24° in 2° increments. Five different configurations will be tested:

a) All perforations temporarily sealed, no blowing.
b) First perforation row open, second perforation row temporarily sealed, no blowing.
c) First perforation row open, second perforation row temporarily sealed, with blowing.
d) Second perforation row open, first perforation row temporarily sealed, no blowing.
e) Second perforation row open, first perforation row temporarily sealed, with blowing.

In all cases the test Reynolds number based on model chord and tunnel speed will be 1.5×10^6. For cases with blowing, the air guage pressure in the forwardmost cell of the model must be maintained at a value within 5% of the wind tunnel's freestream dynamic pressure. For these cases, blowing air supply volumetric flow rates will also be measured. The temporary sealing must be such that it minimally affects aerodynamic performance of the model airfoil section.

3. Test procedures will be prepared and submitted to SNL for its approval prior to initiating the testing. The procedures will include references to methods of calibration of the test equipment.

4. A final report will be prepared and submitted. The report will contain:

   a) A detailed description of the experimental procedure.
   b) A complete set of raw wind tunnel data.
   c) A complete set of reduced wind tunnel data.
   d) A discussion of the means by which the wind tunnel data were reduced.

<u>Period of Performance</u>

Eight months from date of contract.

APPENDIX A.2:

RAW FORCE DATA TABULATION

UW1396 BLOWING WING

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RAW FORCE AND MOMENT DATA

RUN 6

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.14369	-1.4715	-.00700	-85.028	21.196	171.16	7.5978	62.218	7.2146
4	-.05207	.03081	-.01028	13.682	19.414	-21.853	-18.470	79.992	6.2496
5	-.09570	2.0435	-.01003	145.39	18.640	-282.19	-32.588	80.447	6.3257
6	.12173	4.0350	-.01314	275.37	20.078	-532.52	-26.308	81.001	5.5015
7	.06618	6.0226	-.01144	389.43	23.140	-743.36	-34.179	36.112	5.0292
8	-.00505	8.0200	-.01121	458.02	28.284	-821.95	-35.308	28.654	4.5557
9	.04377	10.022	-.01022	494.88	39.383	-857.09	-67.837	4.5938	4.7451
10	.10616	12.009	-.01034	496.71	62.725	-871.92	-70.863	-130.52	4.4379
11	-.22470	14.023	-.01033	460.02	118.06	-1106.2	-326.85	-94.435	1.6625
12	.14777	16.012	-.01026	425.34	164.41	-1279.7	-117.08	-260.01	1.9195
13	.06139	18.032	-.01010	410.91	191.35	-1339.1	-32.522	-238.85	.65157
14	-.24595	20.019	-.00986	405.57	210.66	-1353.8	-75.546	2.9019	-1.2807
15	-.06744	22.027	-.00987	412.37	233.61	-1413.0	-71.781	107.47	-2.2893

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RAW FORCE AND MOMENT DATA

RUN 7

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
9	.06820	-1.4835	-.01031	-87.175	21.343	178.30	9.3398	84.065	8.9254
10	-.02524	.03079	-.01088	12.861	19.618	-17.957	-17.652	105.49	8.5610
11	-.02586	2.0435	-.01051	145.08	19.018	-278.40	-24.113	53.587	9.2474
12	.04058	4.0360	-.01039	275.93	20.366	-533.43	-21.291	45.039	8.9975
13	-.01960	6.0225	-.01036	390.58	23.523	-742.99	-20.132	40.218	7.9668
14	.04414	8.0197	-.01034	458.28	28.884	-819.50	-24.281	-9.7023	8.5894
15	.00002	10.022	-.01032	494.30	39.891	-854.16	-61.233	-33.793	8.5555
16	-.03349	12.009	-.01034	494.86	62.798	-865.31	-65.655	-176.97	8.4047
17	-.06379	14.023	-.01033	461.30	119.67	-1111.7	-295.41	-123.23	5.7673
18	-.03913	16.011	-.01032	420.75	163.74	-1261.5	-115.98	-268.81	5.9273
19	.11205	18.032	-.01020	411.56	191.78	-1336.9	-32.715	-238.68	4.5470
20	.04520	20.035	-.01016	407.84	213.48	-1371.6	-86.730	124.90	1.1345
21	.00140	22.026	-.01015	414.16	234.70	-1412.7	-73.532	93.232	.39585

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RAW FORCE AND MOMENT DATA

RUN 8

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
5	.01379	-1.4833	-.00818	-90.797	19.818	185.96	2.4000	142.23	7.1745
6	.16988	.03081	-.01030	12.466	17.951	-14.183	-21.853	106.42	7.1942
7	-.01284	-1.4837	-.00857	-92.246	19.787	189.85	2.0654	154.64	7.4269
8	.06050	.03077	-.01033	12.362	17.905	-14.895	-23.463	150.34	6.9256
9	.05990	2.0433	-.01029	153.08	16.979	-293.04	-28.561	104.08	7.3216
10	.02759	4.0329	-.01014	292.34	17.484	-579.01	-26.540	111.95	7.1652
11	-.04852	6.0218	-.01016	414.14	20.235	-816.98	-29.502	84.184	7.3639
12	-.02085	8.0196	-.00985	503.51	24.596	-957.89	-34.540	23.607	8.2255
13	-.05775	10.022	-.00784	558.81	34.877	-1024.9	-78.721	266.16	6.1887
14	-.00058	12.009	-.00829	616.01	61.653	-1070.1	-147.41	-61.350	7.6463
15	-.00382	14.022	-.01041	577.09	113.21	-1222.9	-291.08	-273.81	7.6705
16	.05417	16.011	-.01087	525.11	162.69	-1410.7	-242.59	-417.90	6.9810

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RAW FORCE AND MOMENT DATA

RUN 9

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
6	.05203	-1.4835	-.01012	-89.607	20.242	177.69	13.564	154.04	7.0857
7	.07132	.03081	-.01214	13.696	18.512	-19.158	-10.180	98.293	7.3972
8	-.06151	2.0435	-.01195	151.41	17.473	-288.90	-14.101	87.442	7.5554
9	-.04671	4.0348	-.01172	287.82	18.046	-562.53	-15.905	-6.5400	8.5908
10	-.01852	6.0225	-.01211	408.47	20.852	-795.17	-8.0031	-30.984	8.7082
11	.01335	8.0201	-.01086	498.41	25.102	-936.27	2.0223	-101.78	9.5598
12	.03409	10.023	-.01033	555.19	35.763	-1007.9	-13.639	199.96	7.3550
13	.00813	12.010	-.01040	611.68	62.907	-1058.2	-55.480	-58.942	7.8326
14	.05888	14.023	-.01258	574.27	113.55	-1212.2	-231.32	-333.69	8.2886
15	-.01749	16.012	-.01063	526.64	162.97	-1408.4	-218.11	-497.69	7.6318
16	-.04969	18.032	-.01027	476.86	194.67	-1458.6	-63.347	-399.05	6.2346
17	-.06788	20.035	-.01031	447.14	214.53	-1429.1	-35.542	-124.97	3.4915
18	,07810	22.027	-.01015	439.36	237.55	-1463.9	-133.88	385.89	.73342

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RAW FORCE AND MOMENT DATA

RUN 11

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	-.00650	-1.4836	-.01033	-89.964	21.084	176.70	-6.7958	163.23	6.8553
4	-.10606	.03979	-.01320	13.423	19.420	-22.005	-22.978	135.86	6.6646
5	-.04371	2.0488	-.01143	150.23	18.581	-289.53	-27.031	105.25	6.5118
6	-.03271	4.0408	-.01094	285.05	18.976	-556.03	-22.701	17.647	7.2140
7	.01631	6.0319	-.01057	408.35	21.211	-792.25	-13.990	-39.606	7.6040
8	-.05655	8.0262	-.01034	495.45	25.504	-925.81	-3.0261	-110.65	8.5505
9	-.04753	10.033	-.01033	555.25	36.756	-1005.5	-30.889	35.103	6.4914
10	-.00994	12.010	-.01091	611.59	63.898	-1055.7	-26.115	27.335	5.4902
11	.10509	14.022	-.01042	568.93	117.68	-1223.3	-184.11	-75.831	5.2955
12	.01289	16.021	-.01033	523.65	167.23	-1435.6	-171.53	-255.65	5.4527
13	.02759	18.032	-.01034	473.87	194.69	-1436.9	-61.617	-624.32	7.5348
14	-.03310	20.035	-.01033	446.09	215.66	-1422.1	-59.435	-414.40	6.1723
15	.03314	22.027	-.01032	444.11	238.93	-1464.6	-48.574	-471.11	5.8835

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RAW FORCE AND MOMENT DATA

RUN 12

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	-.07106	-1.4838	-.01033	-91.040	20.328	173.87	-33.396	137.48	9.5925
4	-.01681	.04029	-.01285	11.080	18.922	-18.276	-34.545	151.64	9.1789
5	.04951	2.0491	-.01146	142.07	18.391	-267.38	-39.511	221.99	9.1405
6	-.02049	4.0408	-.01086	271.29	19.284	-514.69	-39.060	239.72	11.092
7	-.04696	6.0321	-.01054	387.89	22.011	-729.25	-40.696	142.85	13.732
8	-.01765	8.0265	-.01047	464.43	26.789	-826.16	-42.971	16.449	17.663
9	.02639	10.033	-.01030	493.46	37.651	-840.67	-74.092	-119.39	19.499
10	.01148	12.019	-.01052	487.58	62.650	-880.96	-87.090	-26.978	17.746

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RAW FORCE AND MOMENT DATA

RUN 14

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.00120	-1.4834	-.01025	-86.302	20.192	165.70	-10.334	86.092	5.8805
4	.04998	.03081	-.01165	12.131	18.756	-20.001	-14.674	73.805	5.8344
5	.08054	2.0434	-.01079	145.86	18.019	-278.10	-13.325	61.641	5.7830
6	-.02107	4.0408	-.01035	277.86	18.649	-538.30	-10.728	12.268	6.6020
7	.00942	6.0224	-.01060	402.08	21.141	-782.50	-9.6746	-42.591	7.2186
8	.02549	8.0197	-.01034	493.86	25.196	-927.61	-11.182	-141.08	8.0879
9	.00785	10.022	-.01033	552.24	35.739	-1003.0	-49.600	-5.8640	6.9725
10	.02202	12.009	-.01033	610.06	62.381	-1053.8	-79.193	-69.048	6.3290
11	-.00457	14.022	-.01033	568.51	114.05	-1208.5	-189.66	-166.01	5.9930
12	-.06512	16.011	-.01032	522.54	163.42	-1417.9	-161.24	-287.90	4.9191
13	.03740	18.032	-.01023	473.35	193.53	-1448.7	-15.833	-526.53	4.8859
14	-.01362	20.035	-.01004	449.48	215.00	-1445.5	36.153	-271.45	2.4602
15	.03163	22.026	-.01026	448.85	237.68	-1480.7	-31.958	-154.56	2.3518

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RUN 15

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.04287	-1.4837	-.01021	-89.269	20.112	170.22	-11.702	124.28	.23307
4	.00862	.03077	-.01261	10.260	18.902	-16.481	-20.726	98.347	.01125
5	.03675	2.0435	-.01156	139.28	18.539	-262.25	-33.836	36.414	-.36681
6	.04381	4.0408	-.01055	267.98	19.710	-511.49	-41.003	1.0632	-.38354
7	-.08954	6.0325	-.01066	384.62	22.677	-729.80	-50.601	-132.14	.16276
8	.08279	8.0265	-.01033	460.81	27.579	-827.74	-57.866	-186.48	.50248
9	-.04261	10.022	-.01036	490.93	38.146	-848.73	-82.504	-278.52	.39523
10	-.02683	12.009	-.01153	477.24	64.987	-895.72	-81.666	-162.48	.38154
11	-.03384	14.022	-.01032	452.68	98.962	-975.59	-124.61	-134.39	.46799
12	.00673	16.021	-.00921	461.26	161.42	-1332.0	-107.90	-68.632	.77315
13	.03346	18.032	-.01010	435.78	190.37	-1380.1	-19.972	-51.805	.38628
14	-.03781	20.035	-.01023	417.73	211.67	-1385.2	-41.117	13.778	-.25653
15	.03572	22.026	-.01002	413.22	233.26	-1416.0	-84.164	12.648	.54667

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RUN 16

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
5	-.03319	-1.4833	-.00819	-83.335	20.153	161.61	2.3304	153.99	3.3260
6	.19992	.04075	-.01038	15.351	19.044	-26.113	-6.1512	103.11	2.9878
7	-.04960	2.0490	-.01033	144.49	18.415	-275.11	-9.6304	140.05	3.2960
8	-.06052	4.0408	-.01032	273.98	19.511	-526.74	-9.1532	108.83	3.9367

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RUN 17

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
2	.09739	-1.4831	-.00836	-83.532	20.191	161.92	1.1128	165.13	3.3411
3	-.06656	.04059	-.01041	13.726	18.947	-23.185	-5.9768	124.26	3.0711
4	.04969	2.0493	-.01033	143.97	18.436	-273.33	-8.5900	136.26	3.3055
5	-.05585	4.0408	-.01031	274.41	19.450	-526.90	-8.2647	123.33	3.9732
6	-.03387	6.0324	-.01023	393.79	22.303	-752.71	-9.1264	46.505	4.3889
7	-.03865	8.0268	-.01004	478.68	26.993	-876.25	-12.575	-54.621	4.8191
8	.01330	10.033	-.00834	516.52	37.523	-899.77	-51.268	-106.42	4.5889
9	-.03199	12.020	-.00960	513.07	58.586	-881.56	-48.273	-150.59	3.7779
10	.00762	14.035	-.00890	489.56	116.49	-1137.0	-191.97	-155.24	4.3574
11	-.01098	16.021	-.00839	459.67	164.21	-1335.5	-84.926	-193.28	4.5256
12	-.00488	18.032	-.00921	434.74	190.54	-1369.2	-8.9704	-226.49	3.8974
13	-.00122	20.035	-.00878	421.26	211.97	-1384.7	-9.9479	84.698	2.9720
14	.04157	22.032	-.00777	414.29	233.35	-1415.0	-19.294	-83.738	3.9661

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RUN 18

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	-.00375	-1.4838	-.00810	-83.198	20.033	161.57	-1.1395	245.62	4.6339
4	-.10583	.03889	-.01036	13.689	18.924	-23.157	-7.1564	140.15	4.3610
5	-.09249	2.0488	-.01033	144.69	18.442	-276.00	-10.710	167.49	4.3097
6	-.14262	4.0408	-.01030	274.25	19.486	-528.34	-10.443	172.71	4.6054
7	.02436	6.0322	-.01029	395.44	22.358	-757.29	-10.309	53.355	4.9350
8	-.02572	8.0260	-.01017	480.10	26.938	-881.23	-12.903	-46.888	5.4541
9	.02673	10.033	-.00872	519.34	37.273	-906.02	-48.036	-117.45	5.6367
10	-.01299	12.009	-.01033	520.43	58.050	-888.40	-41.218	-183.47	5.5071
11	-.04083	14.034	-.00941	492.07	117.17	-1142.4	-188.00	-219.68	5.4969
12	-.02116	16.021	-.00915	460.87	164.89	-1342.0	-97.496	-283.05	5.0913
13	-.03840	18.032	-.01012	425.47	191.39	-1363.6	14.901	-491.24	4.0201
14	.01230	20.035	-.01016	412.22	211.26	-1368.0	13.568	-298.84	3.7281
15	-.03434	22.033	-.00826	414.36	233.11	-1415.8	-24.133	-62.322	4.4658

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RUN 20

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
4	.00668	-1.5186	-.00817	-86.096	20.216	161.58	-10.008	238.05	3.8431
5	.03186	.01010	-.01033	10.394	18.911	-18.187	-14.988	143.58	3.6382
6	-.04003	2.0230	-.01033	140.11	18.142	-265.36	-25.111	164.12	4.0917
7	-.00039	4.0010	-.01032	268.14	19.172	-512.87	-29.880	119.08	3.7382
8	.02108	5.9927	-.01002	389.35	22.268	-742.81	-21.022	61.378	3.7402
9	.00291	7.9995	-.01020	466.36	27.082	-845.21	-33.296	-68.034	4.5944
10	.00612	10.005	-.01010	498.21	37.685	-862.45	-60.139	-208.71	4.3139
11	.02521	11.984	-.00974	485.67	62.313	-880.07	-58.836	-228.55	3.9913
12	.02108	13.988	-.01001	464.57	102.20	-1010.5	-190.14	-185.36	4.3234
13	-.10099	15.973	-.00959	453.05	161.72	-1319.3	-143.73	-385.79	4.4139
14	.05564	18.015	-.00857	420.93	190.89	-1364.1	32.229	-404.04	3.3255
15	-.03381	20.012	-.00887	416.22	210.90	-1370.9	-.10704	-551.57	4.0762
16	-.06441	22.006	-.00848	416.74	232.30	-1413.7	3.3107	-323.63	3.9857

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RUN 21

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.06753	-1.5179	-.00808	-90.994	19.972	173.95	4.1507	205.85	2.7671
4	.03719	.01049	-.01034	10.094	18.734	-17.307	-1.2607	191.68	2.1815
5	-.02584	2.0230	-.01033	144.35	18.074	-278.42	-9.6378	187.25	1.6756
6	.04407	4.0011	-.01033	275.42	18.824	-534.65	-17.795	72.749	1.4602
7	-.06353	5.9934	-.01033	401.55	21.221	-783.20	-20.401	19.076	1.5407
8	.02140	7.9995	-.01028	492.76	25.596	-928.07	-27.730	-72.762	1.5409
9	-.01626	10.012	-.00878	542.16	35.086	-986.12	-57.909	-2.8897	1.4271
10	-.00463	11.984	-.00999	593.35	62.883	-1029.7	-88.843	-132.94	.13286
11	.00670	13.999	-.00997	555.87	110.82	-1165.9	-181.03	-89.694	1.0575
12	-.00220	15.983	-.01008	534.24	162.54	-1443.2	-109.79	-38.463	1.8198
13	.04668	18.015	-.00885	505.58	196.79	-1549.5	-93.155	18.267	3.0061
14	.07210	20.011	-.00858	482.21	216.35	-1494.7	-21.248	-535.47	2.5531
15	-.01352	22.013	-.00795	441.16	235.95	-1465.7	-89.971	301.63	2.8687

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RUN 22

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	-.05971	-1.5167	-.00916	-90.306	19.975	173.28	4.0808	210.20	2.8965
4	.01863	.01066	-.01133	7.8168	18.772	-13.140	-10.060	193.36	4.1129
5	.05066	2.0230	-.01063	138.18	18.216	-261.86	-16.942	150.08	3.9949
6	-.00754	4.0151	-.01033	267.56	19.232	-513.39	-25.268	98.487	4.0910
7	-.06883	5.9944	-.01034	386.82	22.180	-741.36	-30.651	73.274	4.3086
8	.00708	7.9995	-.01033	470.73	26.585	-860.64	-35.743	-8.0767	4.9260
9	.00665	10.012	-.00913	512.90	35.710	-902.77	-58.918	-73.324	5.1857
10	.02822	11.984	-.01026	526.19	59.078	-911.41	-68.052	-141.94	4.8209
11	.04959	13.998	-.01003	506.64	115.29	-1158.8	-144.82	134.48	4.7056
12	-.00244	15.983	-.00995	497.00	163.64	-1417.2	-35.334	211.03	4.5660
13	.00798	18.015	-.00842	468.39	190.52	-1426.1	31.282	-116.60	3.3571
14	-.03579	20.011	-.00842	462.11	212.66	-1436.2	30.167	-376.11	3.4156
15	-.04323	22.013	-.00801	429.60	233.02	-1436.6	-142.25	813.83	5.3569

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RUN 23

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
4	.03489	-1.5270	-.01029	-86.524	19.945	170.88	2.2701	129.61	2.2534
5	.02983	.01077	-.01057	12.211	18.922	-19.658	-2.4113	191.76	2.1667
6	-.02224	2.0230	-.01080	142.74	18.374	-273.98	-9.0238	176.43	2.5184
7	-.01191	4.0151	-.01035	272.27	19.339	-525.35	-9.4490	138.76	3.1615
8	.01516	5.9930	-.01034	395.25	22.079	-762.10	-8.7949	46.311	3.7005
9	.03466	7.9995	-.01037	485.91	26.469	-903.25	-10.292	-31.807	4.3136
10	-.06153	10.012	-.00915	529.38	35.747	-944.31	-40.810	-90.947	4.3312
11	-.07329	11.984	-.01018	557.32	60.194	-958.71	-64.492	-192.21	3.6931
12	.04648	13.998	-.01021	529.74	114.68	-1167.2	-167.09	-149.24	3.7994
13	.01422	15.983	-.01026	508.85	164.45	-1430.6	-105.69	-128.14	3.9108
14	-.01702	18.016	-.00917	467.26	191.38	-1436.1	1.7111	-180.27	3.4518
15	-.03273	20.012	-.00887	466.62	213.79	-1447.0	52.129	-608.60	2.3360
16	-.01573	22.013	-.00825	448.16	234.42	-1454.3	-22.882	-62.932	1.3939

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RUN 24

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
2	.00007	-1.5267	-.01033	-85.907	20.319	161.54	-18.263	181.79	5.4308
3	-.00826	.01105	-.01181	12.764	18.985	-21.993	-29.701	188.10	6.3354
4	-.09946	2.0230	-.01105	142.68	18.231	-270.07	-35.944	219.76	6.4124
5	-.00215	-1.5165	-.00992	-84.461	20.313	157.30	-21.929	237.95	6.2486
6	-.04848	.01083	-.01178	12.358	19.015	-20.788	-27.477	170.47	6.0891
7	.01644	2.0230	-.01040	143.19	18.253	-271.18	-36.161	194.72	6.2193
8	.00899	4.0151	-.01041	270.83	19.027	-517.99	-39.399	149.20	6.1415
9	.01465	5.9934	-.01038	388.89	21.823	-740.93	-39.721	94.768	6.2739
10	-.10196	7.9995	-.01036	468.30	26.168	-850.79	-39.953	4.3031	6.5360
11	-.00942	10.012	-.00951	512.64	35.394	-900.39	-59.806	-8.1140	6.1163
12	.02902	11.984	-.01019	526.38	59.009	-914.49	-64.300	-59.269	5.6388
13	-.00603	13.998	-.01026	506.84	114.19	-1153.4	-126.37	172.12	5.3989
14	.01663	15.983	-.01027	491.46	163.84	-1412.6	-46.894	322.90	5.6919
15	-.06335	18.015	-.00934	452.92	188.40	-1390.9	13.091	176.15	4.2173
16	-.03403	20.013	-.00920	457.76	212.44	-1429.4	25.961	-261.68	3.6564
17	.00494	22.014	-.00845	437.17	232.47	-1428.2	-54.003	120.70	3.2633

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RAW FORCE AND MOMENT DATA

RUN 25

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.04713	-1.5171	-.01006	-84.697	20.466	164.45	2.5630	156.47	2.8271
4	-.00663	.01057	-.01184	12.415	19.281	-19.236	-1.7542	117.35	2.5649
5	.04386	2.0230	-.01117	141.43	18.812	-270.52	-8.2404	147.56	2.7554
6	-.07276	4.0151	-.01043	267.93	20.337	-513.30	-8.9510	128.25	3.3237
7	.00326	5.9925	-.01044	382.27	23.650	-724.98	-8.7979	68.951	3.6480
8	.00097	7.9994	-.01038	450.97	28.937	-803.48	-12.565	18.042	4.3389
9	.03492	10.012	-.00983	487.84	39.685	-849.47	-17.884	44.286	4.3440
10	-.03366	11.984	-.01033	488.77	63.134	-874.54	-43.361	-93.958	3.8852
11	.08526	13.998	-.01029	461.10	115.79	-1097.4	-142.27	-51.482	4.1477
12	-.04215	15.982	-.01028	432.98	162.15	-1285.4	-69.607	-232.66	4.0342
13	.02330	18.014	-.00936	420.37	188.55	-1327.6	8.9436	-780.26	3.5812
14	.03152	20.011	-.00946	424.28	208.63	-1352.5	53.453	-697.45	3.4181
15	-.06200	22.013	-.00838	414.98	228.52	-1376.4	-42.159	200.05	3.5997
19	-.03025	-1.5270	-.01031	-85.326	20.453	165.77	2.3221	163.60	2.8537
20	.05464	.01150	-.01191	11.753	19.293	-18.961	-2.8274	130.73	2.5970

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RAW FORCE AND MOMENT DATA

RUN 26

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.10399	-1.5270	-.01032	-85.448	20.496	166.10	.85333	201.55	2.8506
4	.00273	.01053	-.01052	11.998	19.266	-19.195	-3.2572	134.61	2.5827
5	.05707	2.0230	-.01094	140.06	18.832	-268.00	-7.9847	168.91	2.8216
6	-.00803	4.0151	-.01036	267.39	20.470	-511.23	-10.143	92.776	3.3718
7	.00068	5.9927	-.01045	378.72	24.022	-713.31	-8.5422	54.314	3.6374
8	-.04842	7.9995	-.01036	444.54	29.415	-784.70	-12.250	-31.297	4.2688
9	-.08663	10.012	-.00982	485.32	39.626	-840.18	-36.855	-91.384	4.2065
10	.03342	11.999	-.01026	504.12	57.262	-898.69	-78.745	-270.19	3.7239
11	-.00279	13.998	-.01025	488.18	94.638	-1030.2	-196.95	-459.04	3.6633
12	.04728	15.982	-.00995	493.28	147.36	-1315.0	-234.00	104.23	4.1447
13	.10987	18.014	-.00947	497.87	188.70	-1492.6	-81.912	-296.69	4.5902
14	.01646	20.011	-.01026	470.12	210.73	-1455.8	-3.3241	-513.36	4.6870
15	.03410	22.012	-.00863	449.52	230.17	-1434.8	42.277	-574.24	4.0753

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RUN 28

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	-.03313	-1.5160	-.00980	-83.374	20.282	160.23	1.5743	130.48	2.8561
4	-.04307	.00052	-.01041	11.714	19.308	-21.097	-2.5108	170.20	2.6397
5	.03210	2.0122	-.01033	140.14	18.895	-268.60	-5.8229	162.76	2.6709
6	.01333	4.0022	-.00988	266.87	20.495	-511.15	-6.5796	120.99	3.2613
7	-.08577	5.9927	-.00937	380.49	23.868	-721.29	-6.4845	30.831	3.7028
8	.05043	7.9908	-.01025	449.32	29.331	-799.76	-9.5468	-52.336	4.3227
9	.03871	10.006	-.00789	484.14	40.192	-835.24	-32.463	-65.190	4.3529
10	.01569	11.984	-.00794	483.97	64.085	-859.32	-26.197	-134.86	3.9717
11	-.03847	13.989	-.00798	448.57	114.68	-1062.5	-145.57	-246.32	4.0819
12	-.09519	15.973	-.00819	415.45	160.87	-1234.0	-19.653	-918.91	3.5759
13	.14191	17.999	-.00855	404.91	191.34	-1334.6	-13.858	-115.57	3.8023
14	.02409	20.011	-.00781	403.39	211.08	-1354.4	-3.1084	-74.537	3.6986
15	.02131	22.006	-.00778	413.17	233.62	-1410.7	-2.8483	-44.115	3.5972

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RAW FORCE AND MOMENT DATA

RUN 29

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.15822	-1.5172	-.00892	-89.468	20.338	169.44	12.649	208.13	3.2762
4	-.01096	.00110	-.01149	9.7395	18.964	-19.385	7.1178	159.05	2.6599
5	.01266	2.0125	-.01033	143.44	18.275	-277.37	-5.0841	154.38	2.1944
6	-.01960	4.0029	-.01030	276.14	19.046	-538.06	-10.645	102.04	1.8632
7	.05295	5.9936	-.01020	399.59	21.757	-778.86	-13.876	23.213	1.6029
8	.02955	7.9918	-.01033	487.69	26.153	-913.80	-19.899	-53.440	1.7809
9	.01405	10.006	-.00995	539.28	37.068	-973.42	-62.112	46.921	1.5989
10	.03938	11.984	-.00922	583.41	64.481	-1001.2	-79.779	-6.1642	.22123
11	-.01826	13.989	-.00815	549.03	115.13	-1200.1	-203.67	-4.9598	1.2426
12	-.09456	15.973	-.00902	502.37	164.95	-1401.7	-117.87	-477.93	1.1476
13	-.07577	18.001	-.00939	430.71	191.96	-1369.3	-14.968	-834.19	1.4555
14	-.02881	20.012	-.00803	428.42	213.87	-1403.7	58.088	-649.40	.37466
15	.03890	22.006	-.00809	425.43	237.70	-1459.9	-63.415	69.599	2.0195

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RAW FORCE AND MOMENT DATA

RUN 30

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.02294	-1.5176	-.00915	-90.394	19.868	173.54	9.2926	221.54	3.4681
4	.00752	.00037	-.01128	9.4560	18.679	-17.610	3.0163	183.96	2.7647
5	.00937	2.0230	-.01033	143.88	18.206	-278.47	-5.1094	222.53	2.4215
6	.01668	4.0016	-.01032	275.50	18.977	-536.21	-12.404	142.30	2.1648
7	-.01197	5.9933	-.01020	398.42	21.652	-776.54	-18.761	34.116	1.9433
8	.08853	7.9994	-.01026	486.79	26.041	-910.72	-26.403	-41.228	1.9065
9	-.10143	10.006	-.01006	539.04	36.639	-971.63	-68.857	83.537	1.6963
10	-.09453	11.978	-.00954	580.62	62.015	-994.04	-91.530	24.372	.27607
11	-.04519	13.990	-.00981	549.34	115.58	-1200.4	-196.96	-106.18	1.1245
12	.01848	15.973	-.00949	513.59	166.13	-1427.3	-113.26	-409.96	1.5667
13	.05980	17.999	-.00992	435.38	190.84	-1360.5	-15.306	-993.79	1.7045
14	-.01088	19.999	-.00887	418.30	214.04	-1397.2	6.5395	-234.26	1.7989
15	-.01478	22.006	-.00860	422.82	236.82	-1453.0	-60.473	74.640	2.3471

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RAW FORCE AND MOMENT DATA

RUN 31

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	.02993	-1.5170	-.00925	-91.417	19.743	175.49	4.7556	236.38	3.4498
4	.05970	.01075	-.01033	8.4701	18.673	-16.035	-4.7437	224.98	3.9894
5	.01237	-1.5174	-.01031	-93.045	19.773	176.87	2.6803	234.46	4.3172
6	-.01412	.01062	-.01035	8.5913	18.652	-17.712	-6.7535	311.53	4.1713
7	-.05144	2.0230	-.01034	138.11	18.142	-261.82	-14.603	206.39	4.4722
8	.06941	4.0026	-.01033	267.90	19.321	-513.33	-23.861	145.11	4.4526
9	.02960	5.9939	-.01033	387.44	22.280	-739.35	-31.181	59.035	4.8592
10	.01573	7.9994	-.01030	462.44	27.054	-835.51	-39.545	-47.324	5.3504
11	-.06172	10.006	-.01022	491.91	38.510	-860.01	-62.462	-134.43	5.1754
12	.02878	11.984	-.00973	477.27	64.319	-892.32	-53.184	-68.336	5.0576
13	-.03239	13.999	-.00977	449.51	97.641	-959.67	-85.655	-65.052	4.7871
14	.02972	15.983	-.00979	459.43	161.30	-1324.3	-93.664	-198.30	4.9288
15	-.01792	18.015	-.00864	417.51	189.25	-1344.1	-38.219	192.43	4.7759
16	.02648	20.012	-.00828	408.31	210.96	-1366.8	-48.137	163.74	4.6089
17	.01872	22.006	-.00835	412.05	232.37	-1406.7	-39.661	126.17	4.3494

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RAW FORCE AND MOMENT DATA

RUN 32

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
3	-.03152	.01090	-.01044	7.5161	18.963	-10.521	4.7794	181.28	2.5910
4	.02600	4.0024	-.01033	272.91	19.102	-529.46	-12.508	145.76	1.9213
5	.09218	7.9994	-.01033	488.12	26.133	-915.00	-23.653	-77.482	1.5949
6	-.08791	11.984	-.00997	581.02	64.602	-999.72	-67.904	-17.024	-.01961
7	.05124	15.983	-.00904	511.35	166.12	-1428.2	-102.30	-278.70	1.2875

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RAW FORCE AND MOMENT DATA
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RUN 33

TP	DELTAQ	ALPHAI	PSI	LIFT	DRAG	PM	YM	RM	SF
2	-.20036	.01125	-.01042	1.9325	6.0789	-35.775	-2.5281	-10.923	1.0349

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APPENDIX A.3:

REDUCED FORCE DATA TABULATION

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 6

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	61.991	-1.5732	-.00700	-.15057	.03796	.00234	.00027	.00087	.01310
4	61.789	.03329	-.01028	.02506	.03463	-.00417	-.00017	.00117	.01141
5	61.745	2.1855	-.01003	.26031	.03389	-.01320	-.00040	.00114	.01158
6	61.964	4.3137	-.01314	.49074	.03806	-.01967	-.00031	.00113	.01010
7	61.908	6.4221	-.01144	.69444	.04600	-.02261	-.00045	.00035	.00932
8	61.837	8.4925	-.01121	.81769	.05712	-.01571	-.00048	.00022	.00852
9	61.908	10.533	-.01022	.88270	.07794	-.01050	-.00102	-.00020	.00894
10	62.096	12.521	-.01034	.88381	.11918	-.01309	-.00110	-.00245	.00856
11	62.077	14.495	-.01033	.82014	.21628	-.06339	-.00546	-.00180	.00407
12	62.715	16.443	-.01026	.75192	.29446	-.10123	-.00200	-.00455	.00496
13	62.779	18.448	-.01010	.72643	.34104	-.11361	-.00068	-.00419	.00295
14	62.578	20.431	-.00986	.71983	.37598	-.11577	-.00147	-.00018	-.00035
15	62.880	22.444	-.00987	.72883	.41451	-.12046	-.00145	.00154	-.00194

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 7

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
9	72.169	-1.5745	-.01031	-.13555	.02346	.00796	.00031	.00120	.01230
10	72.069	.03046	-.01088	.01730	.02063	.00216	-.00008	.00150	.01175
11	72.069	2.1632	-.01051	.21962	.02017	-.00566	-.00014	.00071	.01284
12	72.135	4.2743	-.01039	.41950	.02349	-.01173	-.00010	.00056	.01248
13	72.075	6.3650	-.01036	.59532	.03015	-.01396	-.00010	.00048	.01095
14	72.139	8.4233	-.01034	.69843	.03968	-.00809	-.00015	-.00026	.01194
15	72.132	10.459	-.01032	.75381	.05733	-.00379	-.00068	-.00061	.01196
16	72.222	12.446	-.01034	.75418	.09222	-.00586	-.00076	-.00267	.01189
17	72.511	14.427	-.01033	.70123	.17748	-.04996	-.00412	-.00185	.00822
18	72.786	16.378	-.01032	.63802	.24265	-.08101	-.00160	-.00393	.00881
19	73.093	18.388	-.01020	.62205	.28369	-.09239	-.00048	-.00348	.00689
20	73.145	20.387	-.01016	.61644	.31604	-.09612	-.00134	.00171	.00182
21	73.215	22.384	-.01015	.62579	.34778	-.09843	-.00119	.00125	.00065

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 8

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
5	72.106	-1.5777	-.00818	-.14126	.02115	.00868	.00017	.00208	.00959
6	72.257	.03009	-.01030	.01659	.01803	.00288	-.00016	.00154	.00960
7	72.079	-1.5794	-.00857	-.14353	.02112	.00895	.00018	.00225	.00998
8	72.147	.02998	-.01033	.01646	.01798	.00285	-.00019	.00218	.00920
9	72.146	2.1701	-.01029	.23155	.01707	-.00553	-.00025	.00147	.00984
10	72.114	4.2861	-.01014	.44462	.01930	-.01372	-.00021	.00155	.00964
11	72.038	6.3859	-.01016	.63162	.02558	-.01804	-.00025	.00112	.01001
12	72.065	8.4647	-.00985	.76824	.03421	-.01561	-.00030	.00021	.01138
13	72.028	10.518	-.00784	.85354	.05133	-.01052	-.00098	.00372	.00829
14	72.209	12.556	-.00829	.93933	.09370	-.00481	-.00194	-.00103	.01071
15	72.500	14.531	-.01041	.87736	.17056	-.03717	-.00400	-.00406	.01111
16	72.845	16.471	-.01087	.79548	.24321	-.07599	-.00335	-.00608	.01042

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 9

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
6	72.147	-1.5768	-.01012	-.13935	.02178	.00776	.00033	.00225	.00945
7	72.160	.03122	-.01214	.01051	.01891	.00236	+0	.00142	.00994
8	72.027	2.1690	-.01195	.22938	.01785	-.00544	-.00004	.00123	.01022
9	72.042	4.2842	-.01172	.43818	.02014	-.01279	-.00003	-.00018	.01107
10	72.070	6.3812	-.01211	.62269	.02642	-.01666	.00009	-.00056	.01209
11	72.102	8.4603	-.01086	.76008	.03486	-.01416	.00026	-.00161	.01345
12	72.125	10.515	-.01033	.84691	.05252	-.00931	-.00002	.00274	.01009
13	72.226	12.552	-.01040	.93253	.09546	-.00436	-.00063	-.00100	.01101
14	72.566	14.529	-.01258	.87230	.17084	-.03651	-.00314	-.00492	.01206
15	72.774	16.474	-.01063	.79860	.24392	-.07556	-.00300	-.00723	.01143
16	72.929	18.448	-.01027	.72227	.29009	-.09335	-.00087	-.00580	.00953
17	73.027	20.424	-.01031	.67683	.31896	-.09467	-.00056	-.00188	.00545
18	73.301	22.407	-.01015	.66308	.35213	-.09857	-.00203	.00538	.00136

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RUN 11

TF	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.093	-1.5772	-.01033	-.13999	.02300	.00743	.00004	.00239	.00910
4	71.988	.03939	-.01320	.01015	.02034	.00183	-.00019	.00198	.00883
5	72.050	2.1732	-.01143	.22751	.01952	-.00592	-.00024	.00151	.00861
6	72.061	4.2876	-.01094	.43382	.02151	-.01262	-.00016	.00020	.00974
7	72.110	6.3904	-.01057	.62214	.02695	-.01636	-.00002	-.00066	.01038
8	72.037	8.4642	-.01034	.75622	.03544	-.01351	.00016	-.00172	.01190
9	72.048	10.525	-.01033	.84788	.05412	-.00940	-.00029	.00039	.00879
10	72.214	12.552	-.01091	.93254	.09696	-.00405	-.00027	.00027	.00741
11	72.636	14.523	-.01042	.86342	.17675	-.03924	-.00255	-.00120	.00748
12	72.828	16.479	-.01033	.79355	.25007	-.07979	-.00239	-.00376	.00812
13	73.008	18.445	-.01034	.71699	.28978	-.09153	-.00081	-.00901	.01151
14	73.069	20.422	-.01033	.67408	.32051	-.09455	-.00083	-.00601	.00956
15	73.263	22.411	-.01032	.67058	.35461	-.09898	-.00070	-.00680	.00927

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 12

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.024	-1.5785	-.01033	-.14175	.02197	.00695	-.00029	.00196	.01334
4	72.075	.03835	-.01285	.01458	.01956	.00197	-.00030	.00215	.01270
5	72.142	2.1660	-.01146	.21481	.01915	-.00444	-.00036	.00313	.01264
6	72.072	4.2751	-.01086	.41281	.02178	-.00977	-.00031	.00332	.01570
7	72.045	6.3723	-.01054	.59154	.02780	-.01236	-.00026	.00185	.01984
8	72.075	8.4360	-.01047	.70858	.03668	-.00729	-.00020	-.00005	.02595
9	72.146	10.469	-.01030	.75251	.05392	-.00205	-.00060	-.00203	.02883
10	72.269	12.448	-.01052	.74277	.09177	-.00928	-.00083	-.00066	.02626

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 14

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.096	-1.5737	-.01025	-.13444	.02171	.00673	-.00003	.00130	.00760
4	72.140	.02981	-.01165	.01609	.01929	.00187	-.00009	.00110	.00753
5	72.170	2.1636	-.01079	.22042	.01861	-.00525	-.00006	.00089	.00747
6	72.068	4.2811	-.01035	.42275	.02091	-.01172	-0	.00014	.00879
7	72.099	6.3753	-.01060	.61264	.02672	-.01641	.00003	-.00069	.00979
8	72.115	8.4558	-.01034	.75295	.03489	-.01409	.00003	-.00215	.01117
9	72.099	10.511	-.01033	.84265	.05245	-.00966	-.00055	-.00020	.00952
10	72.238	12.550	-.01033	.92986	.09459	-.00411	-.00100	-.00112	.00869
11	72.507	14.523	-.01033	.86424	.17156	-.03716	-.00261	-.00250	.00854
12	72.730	16.470	-.01032	.79285	.24462	-.07747	-.00226	-.00422	.00728
13	73.011	18.444	-.01023	.71609	.28797	-.09284	-.00023	-.00759	.00746
14	73.084	20.425	-.01004	.67981	.31950	-.09640	.00042	-.00394	.00390
15	73.253	22.415	-.01026	.67777	.35281	-.09926	-.00056	-.00228	.00387

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 15

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.137	-1.5767	-.01021	-.13900	.02156	.00605	-.00017	.00197	-.00112
4	72.099	.02808	-.01261	.01314	.01950	.00200	-.00030	.00158	-.00146
5	72.127	2.1578	-.01156	.21038	.01936	-.00462	-.00049	.00066	-.00201
6	72.134	4.2718	-.01055	.40715	.02237	-.01044	-.00059	.00012	-.00200
7	72.000	6.3700	-.01066	.58662	.02878	-.01363	-.00072	-.00184	-.00110
8	72.173	8.4322	-.01033	.70175	.03773	-.00867	-.00082	-.00265	-.00054
9	72.081	10.456	-.01036	.74895	.05463	-.00395	-.00118	-.00399	-.00063
10	72.246	12.430	-.01153	.72692	.09509	-.01402	-.00119	-.00232	-.00045
11	72.430	14.419	-.01032	.68838	.14597	-.03161	-.00182	-.00193	-.00007
12	72.809	16.424	-.00921	.69909	.23986	-.07997	-.00161	-.00102	.00091
13	73.000	18.411	-.01010	.65937	.28236	-.09186	-.00041	-.00079	.00054
14	73.049	20.397	-.01023	.63212	.31393	-.09556	-.00074	.00015	-.00030
15	73.242	22.384	-.01002	.62411	.34548	-.09904	-.00133	.00011	.00108

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 16

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
5	72.061	-1.5709	-.00819	-.13000	.02163	.00687	.00010	.00233	.00365
6	72.291	.04264	-.01038	.02093	.01967	.00170	-.00003	.00158	.00313
7	72.041	2.1683	-.01033	.21870	.01922	-.00508	-.00007	.00207	.00364
8	72.030	4.2776	-.01032	.41703	.02217	-.01100	-.00004	.00158	.00467

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 17

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
2	72.192	-1.5708	-.00836	-.13006	.02164	.00688	.00008	.00249	.00367
3	72.023	.04106	-.01041	.01853	.01960	.00183	-.00002	.00189	.00327
4	72.140	2.1678	-.01033	.21761	.01922	-.00495	-.00005	.00202	.00365
5	72.034	4.2780	-.01031	.41766	.02208	-.01090	-.00003	.00178	.00473
6	72.056	6.3779	-.01023	.60030	.02834	-.01432	-.00003	.00064	.00542
7	72.051	8.4494	-.01004	.73037	.03730	-.01083	-.00007	-.00084	.00613
8	72.126	10.490	-.00834	.78770	.05425	-.00455	-.00063	-.00159	.00584
9	72.195	12.473	-.00960	.78211	.08625	-.00319	-.00062	-.00222	.00473
10	72.557	14.465	-.00890	.74364	.17316	-.04628	-.00268	-.00230	.00604
11	72.807	16.422	-.00839	.69681	.24409	-.08133	-.00120	-.00285	.00668
12	72.963	18.410	-.00921	.65816	.28279	-.09105	-.00016	-.00331	.00591
13	73.087	20.400	-.00878	.63719	.31429	-.09452	-.00021	.00111	.00462
14	73.248	22.390	-.00777	.62573	.34564	-.09875	-.00033	-.00129	.00629

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 18

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.090	-1.5713	-.00810	-.12970	.02143	.00706	.00007	.00362	.00566
4	71.984	.03933	-.01036	.01850	.01957	.00185	-.00001	.00209	.00527
5	71.997	2.1682	-.01033	.21916	.01927	-.00512	-.00006	.00245	.00521
6	71.947	4.2781	-.01030	.41793	.02216	-.01107	-.00004	.00248	.00571
7	72.114	6.3789	-.01029	.60235	.02843	-.01456	-.00003	.00073	.00626
8	72.064	8.4498	-.01017	.73243	.03724	-.01115	-.00006	-.00074	.00711
9	72.137	10.492	-.00872	.79190	.05393	-.00472	-.00056	-.00177	.00745
10	72.209	12.469	-.01033	.79321	.08561	-.00241	-.00048	-.00272	.00739
11	72.511	14.466	-.00941	.74796	.17438	-.04662	-.00260	-.00324	.00781
12	72.800	16.423	-.00915	.69870	.24519	-.08213	-.00136	-.00413	.00755
13	72.936	18.401	-.01012	.64438	.28403	-.09307	.00018	-.00707	.00613
14	73.099	20.392	-.01016	.62338	.31305	-.09507	.00014	-.00433	.00580
15	73.171	22.391	-.00826	.62650	.34565	-.09890	-.00039	-.00099	.00705

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RUN 20

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
4	72.101	-1.6087	-.00817	-.13413	.02171	.00646	-.00007	.00353	.00444
5	72.122	.00753	-.01033	.01341	.01951	.00187	-.00014	.00215	.00414
6	72.050	2.1382	-.01033	.21197	.01877	-.00461	-.00027	.00240	.00486
7	72.090	4.2324	-.01032	.40773	.02156	-.01035	-.00034	.00173	.00435
8	72.111	6.3340	-.01002	.59305	.02817	-.01397	-.00021	.00087	.00441
9	72.093	8.4106	-.01020	.71110	.03713	-.00952	-.00037	-.00103	.00578
10	72.125	10.445	-.01010	.75970	.05407	-.00397	-.00077	-.00305	.00542
11	72.281	12.411	-.00974	.73943	.09118	-.00986	-.00077	-.00333	.00509
12	72.500	14.395	-.01001	.70593	.15103	-.03395	-.00265	-.00271	.00588
13	72.705	16.369	-.00959	.68764	.24054	-.08101	-.00203	-.00559	.00651
14	73.029	18.380	-.00857	.63668	.28280	-.09392	.00040	-.00581	.00505
15	73.050	20.372	-.00887	.62979	.31283	-.09493	-.00005	-.00791	.00634
16	73.136	22.367	-.00848	.63032	.34468	-.09848	-.00002	-.00468	.00634

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RUN 21

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.161	-1.6124	-.00808	-.14153	.02135	.00716	.00011	.00309	.00278
4	72.126	.00765	-.01034	.01293	.01923	.00204	.00003	.00287	.00189
5	72.063	2.1420	-.01033	.21838	.01868	-.00540	-.00010	.00278	.00113
6	72.133	4.2388	-.01033	.41856	.02110	-.01169	-.00022	.00111	.00084
7	72.025	6.3462	-.01033	.61237	.02684	-.01657	-.00025	.00030	.00102
8	72.110	8.4345	-.01028	.75121	.03545	-.01436	-.00036	-.00105	.00106
9	72.075	10.492	-.00878	.82739	.05119	-.00960	-.00080	-.00006	.00095
10	72.220	12.509	-.00999	.90445	.09489	-.00496	-.00129	-.00193	-.00085
11	72.505	14.488	-.00997	.84489	.16630	-.03404	-.00261	-.00133	.00093
12	72.784	16.451	-.01008	.80995	.24335	-.07745	-.00161	-.00063	.00252
13	73.029	18.456	-.00885	.76468	.29348	-.09769	-.00137	.00015	.00459
14	73.168	20.430	-.00858	.72833	.32189	-.09531	-.00039	-.00768	.00406
15	73.200	22.395	-.00795	.66671	.35025	-.09848	-.00135	.00417	.00461

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RUN 22

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.033	-1.6108	-.00916	-.14072	.02139	.00722	.00011	.00315	.00298
4	72.108	.00575	-.01133	.00949	.01930	.00214	-.00006	.00286	.00487
5	72.140	2.1363	-.01063	.20876	.01885	-.00456	-.00015	.00220	.00471
6	72.081	4.2460	-.01033	.40689	.02165	-.01056	-.00027	.00143	.00490
7	72.020	6.3338	-.01034	.58993	.02803	-.01430	-.00034	.00103	.00529
8	72.096	8.4146	-.01033	.71776	.03646	-.01041	-.00039	-.00017	.00628
9	72.110	10.466	-.00913	.78231	.05140	-.00545	-.00072	-.00113	.00675
10	72.255	12.448	-.01026	.80153	.08725	-.00422	-.00088	-.00211	.00634
11	72.587	14.443	-.01003	.76932	.17162	-.04458	-.00200	.00182	.00655
12	72.801	16.418	-.00995	.75346	.24402	-.08247	-.00049	.00288	.00672
13	72.967	18.423	-.00842	.70900	.28344	-.09023	.00039	-.00175	.00509
14	73.045	20.413	-.00842	.69918	.31641	-.09219	.00036	-.00543	.00534
15	73.157	22.385	-.00801	.64973	.34576	-.09659	-.00202	.01139	.00833

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RUN 23

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
4	72.128	-1.6175	-.01029	-.13478	.02130	.00748	.00007	.00200	.00199
5	72.120	.00985	-.01057	.01618	.01952	.00211	+0	.00287	.00187
6	72.068	2.1405	-.01080	.21593	.01913	-.00521	-.00007	.00261	.00244
7	72.078	4.2502	-.01035	.41411	.02186	-.01110	-.00006	.00202	.00347
8	72.105	6.3396	-.01034	.60210	.02800	-.01523	-.00004	.00065	.00435
9	72.125	8.4282	-.01037	.74066	.03662	-.01268	-.00005	-.00051	.00534
10	72.037	10.481	-.00915	.80832	.05193	-.00723	-.00049	-.00137	.00544
11	72.149	12.477	-.01018	.85028	.08991	-.00358	-.00086	-.00283	.00462
12	72.574	14.464	-.01021	.80450	.17133	-.04076	-.00234	-.00221	.00517
13	72.819	16.428	-.01026	.77117	.24551	-.08208	-.00150	-.00193	.00574
14	72.947	18.423	-.00917	.70750	.28479	-.09199	-.00002	-.00266	.00524
15	73.054	20.418	-.00887	.70589	.31821	-.09295	.00064	-.00872	.00373
16	73.188	22.402	-.00825	.67727	.34821	-.09571	-.00045	-.00098	.00238

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RUN 24

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
2	72.095	-1.6167	-.01033	-.13382	.02189	.00638	-.00015	.00268	.00690
3	72.082	.01064	-.01181	.01711	.01964	.00186	-.00029	.00273	.00830
4	71.990	2.1406	-.01105	.21615	.01894	-.00466	-.00037	.00316	.00845
5	72.093	-1.6051	-.00992	-.13159	.02186	.00618	-.00019	.00347	.00816
6	72.042	.01005	-.01178	.01649	.01970	.00191	-.00027	.00249	.00793
7	72.106	2.1409	-.01040	.21657	.01895	-.00474	-.00038	.00280	.00814
8	72.099	4.2489	-.01041	.41184	.02137	-.01039	-.00042	.00211	.00806
9	72.105	6.3342	-.01038	.59243	.02749	-.01372	-.00042	.00130	.00831
10	71.988	8.4130	-.01036	.71515	.03584	-.00959	-.00042	-.00002	.00877
11	72.092	10.465	-.00951	.78213	.05092	-.00505	-.00071	-.00021	.00818
12	72.255	12.449	-.01019	.80184	.08714	-.00444	-.00081	-.00094	.00759
13	72.525	14.444	-.01026	.77028	.17011	-.04367	-.00173	.00235	.00761
14	72.823	16.413	-.01027	.74488	.24411	-.08301	-.00063	.00446	.00843
15	72.888	18.410	-.00934	.68638	.28017	-.08877	.00016	.00239	.00636
16	73.047	20.411	-.00920	.69262	.31597	-.09215	.00031	-.00382	.00570
17	73.201	22.393	-.00845	.66061	.34496	-.09458	-.00084	.00160	.00519

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RUN 25

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.143	-1.6059	-.01006	-.13193	.02209	.00692	.00009	.00237	.00288
4	72.085	.00983	-.01184	.01650	.02009	.00202	.00003	.00180	.00249
5	72.136	2.1392	-.01117	.21372	.01978	-.00514	-.00006	.00219	.00281
6	72.019	4.2465	-.01043	.40783	.02335	-.01062	-.00005	.00187	.00373
7	72.095	6.3273	-.01044	.58238	.03016	-.01335	-.00004	.00098	.00427
8	72.093	8.3967	-.01038	.68761	.03962	-.00756	-.00008	.00021	.00538
9	72.167	10.442	-.00983	.74348	.05680	-.00443	-.00016	.00058	.00546
10	72.226	12.415	-.01033	.74477	.09256	-.00835	-.00056	-.00140	.00492
11	72.639	14.402	-.01029	.69961	.17123	-.04741	-.00198	-.00081	.00571
12	72.771	16.360	-.01028	.65664	.24053	-.08101	-.00099	-.00339	.00591
13	72.984	18.379	-.00936	.63612	.27949	-.08974	.00008	-.01116	.00545
14	73.101	20.379	-.00946	.64146	.30936	-.09057	.00069	-.00997	.00533
15	73.118	22.373	-.00838	.62783	.33896	-.09297	-.00066	.00273	.00567
19	72.065	-1.6164	-.01031	-.13304	.02209	.00700	.00009	.00248	.00292
20	72.147	.01016	-.01191	.01548	.02009	.00194	.00001	.00198	.00254

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RUN 26

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.200	-1.6164	-.01032	-.13297	.02211	.00706	.00006	.00302	.00291
4	72.095	.00942	-.01052	.01586	.02006	.00197	+0	.00204	.00252
5	72.149	2.1380	-.01094	.21160	.01979	-.00505	-.00005	.00249	.00291
6	72.084	4.2458	-.01036	.40664	.02353	-.01053	-.00007	.00136	.00380
7	72.092	6.3244	-.01045	.57696	.03067	-.01266	-.00004	.00077	.00426
8	72.043	8.3911	-.01036	.67825	.04025	-.00666	-.00008	-.00049	.00528
9	72.046	10.441	-.00982	.74086	.05678	-.00400	-.00044	-.00137	.00526
10	72.257	12.444	-.01026	.76773	.08396	-.00746	-.00106	-.00392	.00464
11	72.428	14.427	-.01025	.74237	.14025	-.03053	-.00276	-.00662	.00483
12	72.764	16.414	-.00995	.74783	.21945	-.06852	-.00330	.00140	.00593
13	73.051	18.448	-.00947	.75263	.28105	-.09176	-.00116	-.00432	.00696
14	73.085	20.420	-.01026	.71086	.31353	-.09271	-.00007	-.00740	.00727
15	73.215	22.402	-.00863	.67895	.34179	-.09325	.00053	-.00823	.00647

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RUN 28

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.062	-1.6037	-.00980	-.13006	.02183	.00662	.00008	.00200	.00293
4	72.049	-.00084	-.01041	.01544	.02013	.00171	.00002	.00255	.00260
5	72.124	2.1273	-.01033	.21178	.01990	-.00514	-.00002	.00241	.00267
6	72.105	4.2323	-.00988	.40572	.02355	-.01059	-.00002	.00176	.00363
7	72.006	6.3264	-.00937	.58036	.03051	-.01336	-0	.00043	.00437
8	72.143	8.3862	-.01025	.68462	.04016	-.00760	-.00004	-.00080	.00536
9	72.175	10.432	-.00789	.73776	.05750	-.00367	-.00037	-.00099	.00548
10	72.282	12.410	-.00794	.73689	.09383	-.00764	-.00031	-.00199	.00506
11	72.512	14.382	-.00798	.68172	.16962	-.04603	-.00204	-.00358	.00562
12	72.716	16.335	-.00819	.63042	.23852	-.07945	-.00030	-.01316	.00526
13	73.122	18.349	-.00855	.61177	.28276	-.09344	-.00023	-.00173	.00575
14	73.112	20.359	-.00781	.60998	.31252	-.09509	-.00010	-.00115	.00573
15	73.230	22.363	-.00778	.62420	.34611	-.09852	-.00011	-.00073	.00573

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PAGE 20.1

FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 29

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.254	-1.6102	-.00892	-.13900	.02187	.00678	.00024	.00310	.00356
4	72.079	-.00206	-.01149	.01241	.01960	.00160	.00015	.00239	.00263
5	72.103	2.1306	-.01033	.21688	.01898	-.00553	-.00002	.00230	.00194
6	72.070	4.2416	-.01030	.42004	.02147	-.01198	-.00011	.00152	.00147
7	72.143	6.3439	-.01020	.60837	.02757	-.01646	-.00016	.00035	.00111
8	72.120	8.4221	-.01033	.74339	.03617	-.01366	-.00024	-.00077	.00144
9	72.117	10.483	-.00995	.82256	.05411	-.00881	-.00086	.00065	.00122
10	72.276	12.500	-.00922	.88864	.09695	-.00352	-.00116	-.00011	-.00072
11	72.505	14.473	-.00815	.83458	.17265	-.04048	-.00293	-.00012	.00124
12	72.715	16.413	-.00902	.76235	.24651	-.08062	-.00175	-.00687	.00154
13	72.901	18.375	-.00939	.65251	.28517	-.09325	-.00031	-.01191	.00224
14	73.068	20.384	-.00803	.64803	.31747	-.09665	.00067	-.00926	.00074
15	73.267	22.374	-.00809	.64241	.35228	-.10200	-.00101	.00090	.00335

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 30

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.115	-1.6116	-.00915	-.14069	.02120	.00726	.00020	.00330	.00386
4	72.096	-.00305	-.01128	.01197	.01916	.00187	.00010	.00275	.00279
5	72.098	2.1415	-.01033	.21757	.01887	-.00546	-.00002	.00327	.00228
6	72.105	4.2396	-.01032	.41887	.02134	-.01179	-.00013	.00209	.00193
7	72.077	6.3429	-.01020	.60715	.02741	-.01639	-.00022	.00051	.00164
8	72.178	8.4286	-.01026	.74142	.03595	-.01340	-.00033	-.00060	.00163
9	71.999	10.484	-.01006	.82353	.05354	-.00853	-.00095	.00118	.00137
10	72.129	12.493	-.00954	.88614	.09331	-.00285	-.00133	.00033	-.00066
11	72.481	14.474	-.00981	.83533	.17343	-.04068	-.00284	-.00156	.00107
12	72.831	16.423	-.00949	.77817	.24816	-.08121	-.00167	-.00590	.00219
13	73.030	18.377	-.00992	.65839	.28309	-.09097	-.00031	-.01416	.00262
14	73.089	20.362	-.00887	.63268	.31738	-.09760	-.00001	-.00339	.00288
15	73.209	22.372	-.00860	.63898	.35119	-.10175	-.00096	.00096	.00384

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PAGE 22.1

FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 31

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.122	-1.6119	-.00925	-.14224	.02101	.00738	.00013	.00351	.00383
4	72.148	.00643	-.01033	.01048	.01913	.00196	.00001	.00331	.00467
5	72.104	-1.6138	-.01031	-.14475	.02107	.00725	.00012	.00347	.00517
6	72.074	.00642	-.01035	.01069	.01911	.00190	-.00001	.00465	.00495
7	72.037	2.1364	-.01034	.20897	.01876	-.00447	-.00011	.00300	.00545
8	72.158	4.2335	-.01033	.40699	.02176	-.01043	-.00024	.00209	.00545
9	72.118	6.3333	-.01033	.59008	.02816	-.01394	-.00033	.00081	.00613
10	72.104	8.4070	-.01030	.70501	.03700	-.00907	-.00044	-.00074	.00694
11	72.063	10.440	-.01022	.75075	.05522	-.00505	-.00078	-.00200	.00675
12	72.298	12.404	-.00973	.72653	.09400	-.01335	-.00067	-.00105	.00674
13	72.425	14.393	-.00977	.68366	.14390	-.03002	-.00116	-.00100	.00656
14	72.832	16.384	-.00979	.69614	.23959	-.07964	-.00131	-.00292	.00727
15	72.947	18.378	-.00864	.63232	.28050	-.09116	-.00055	.00263	.00721
16	73.112	20.365	-.00828	.61744	.31241	-.09513	-.00070	.00221	.00709
17	73.221	22.362	-.00835	.62261	.34422	-.09792	-.00061	.00167	.00684

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FINAL FORCE AND MOMENT COEFFICIENT DATA

RUN 32

TP	QC	ALPHAC	PSI	CLWA	CDWA	CMWA25	CNWA25	CRWA25	CYWA
3	72.058	.00573	-.01044	.00901	.01960	.00237	.00012	.00272	.00252
4	72.116	4.2380	-.01033	.41484	.02149	-.01146	-.00013	.00214	.00155
5	72.183	8.4298	-.01033	.74338	.03612	-.01374	-.00030	-.00111	.00115
6	72.150	12.499	-.00997	.88654	.09725	-.00390	-.00100	-.00026	-.00109
7	72.865	16.430	-.00904	.77444	.24795	-.08158	-.00152	-.00403	.00175

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APPENDIX A.4

PRESSURE PROFILES

A.4-2

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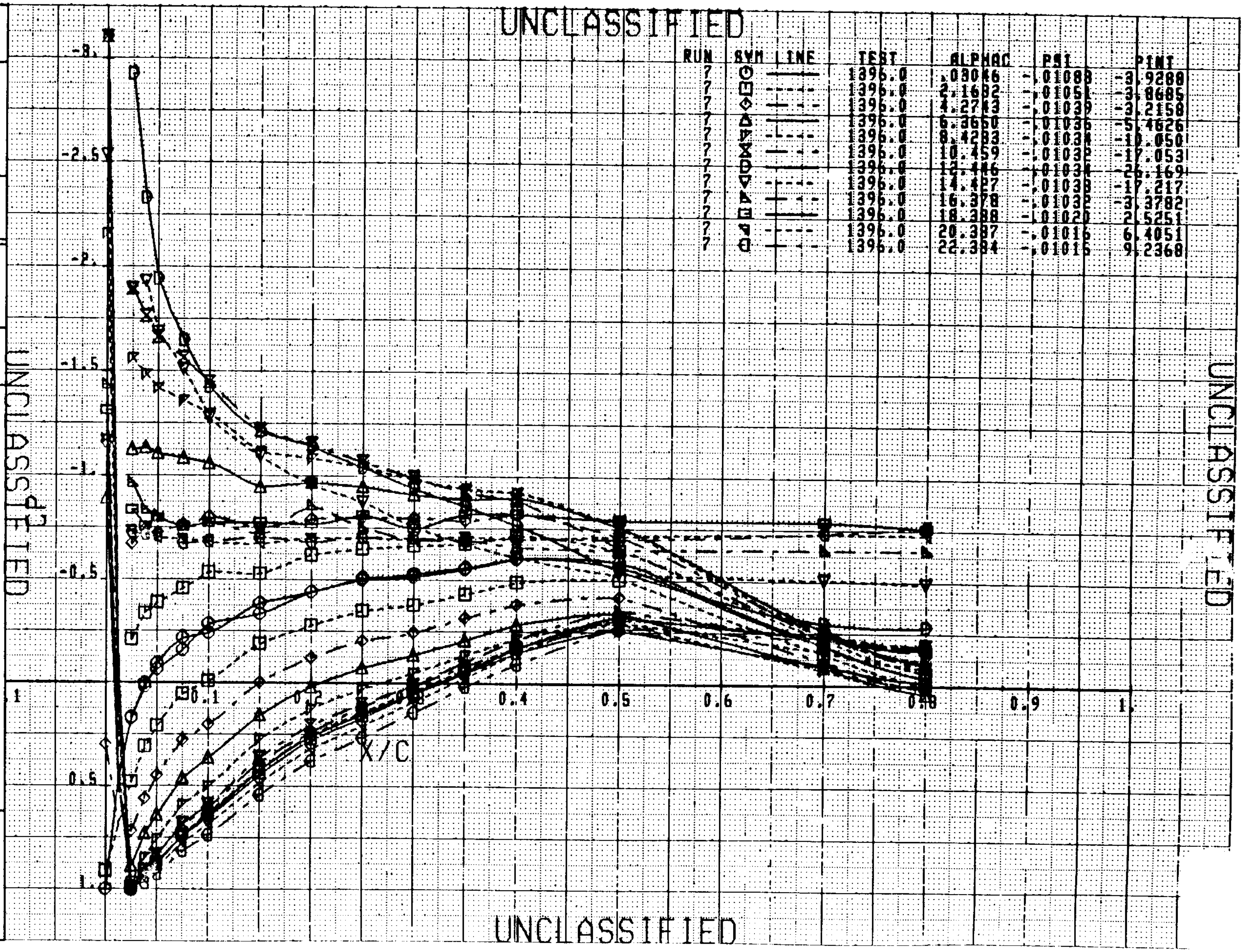

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1850 AIRFOIL

UW AERO LABORATORY

UW1396

FIGURE

PAGE

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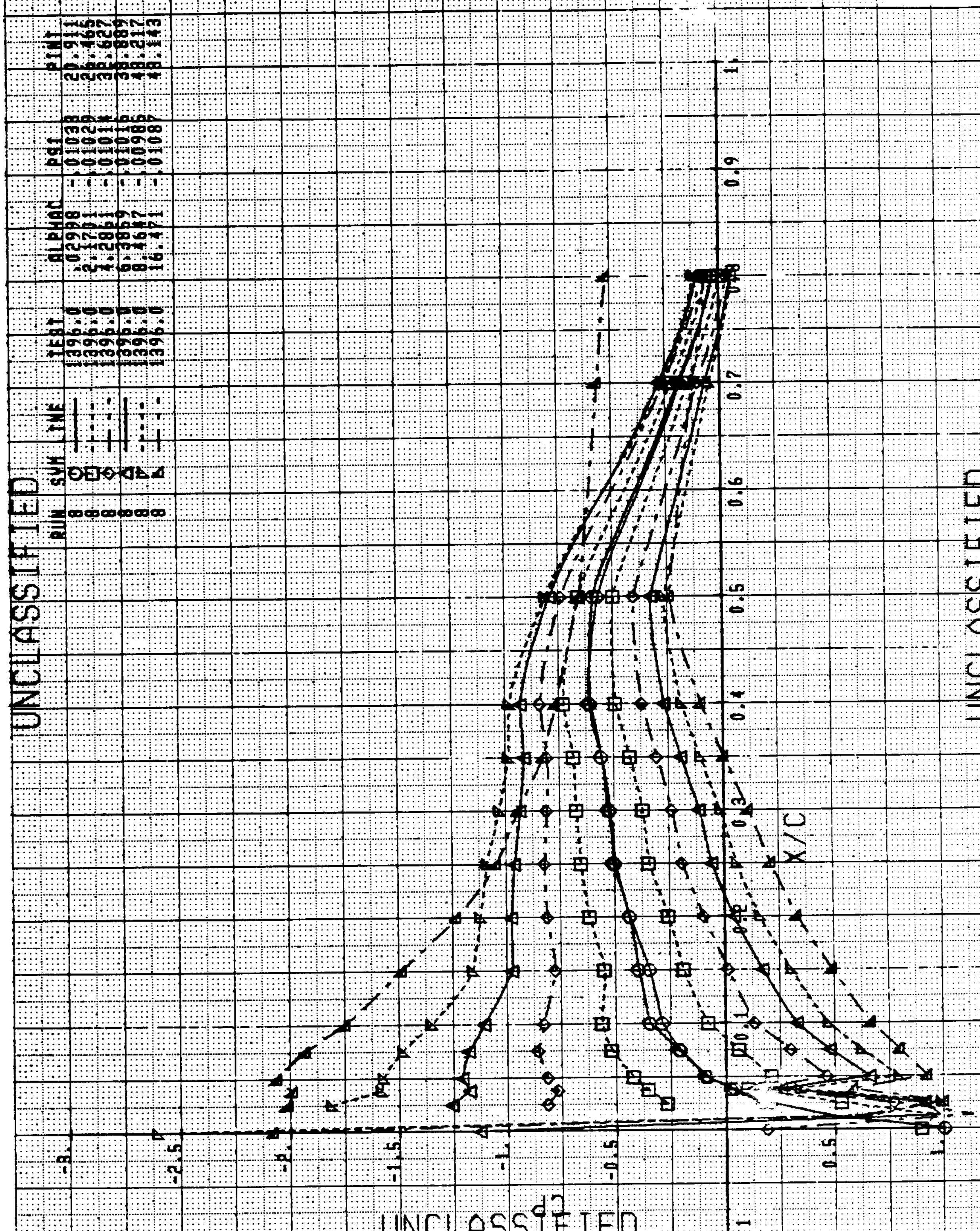

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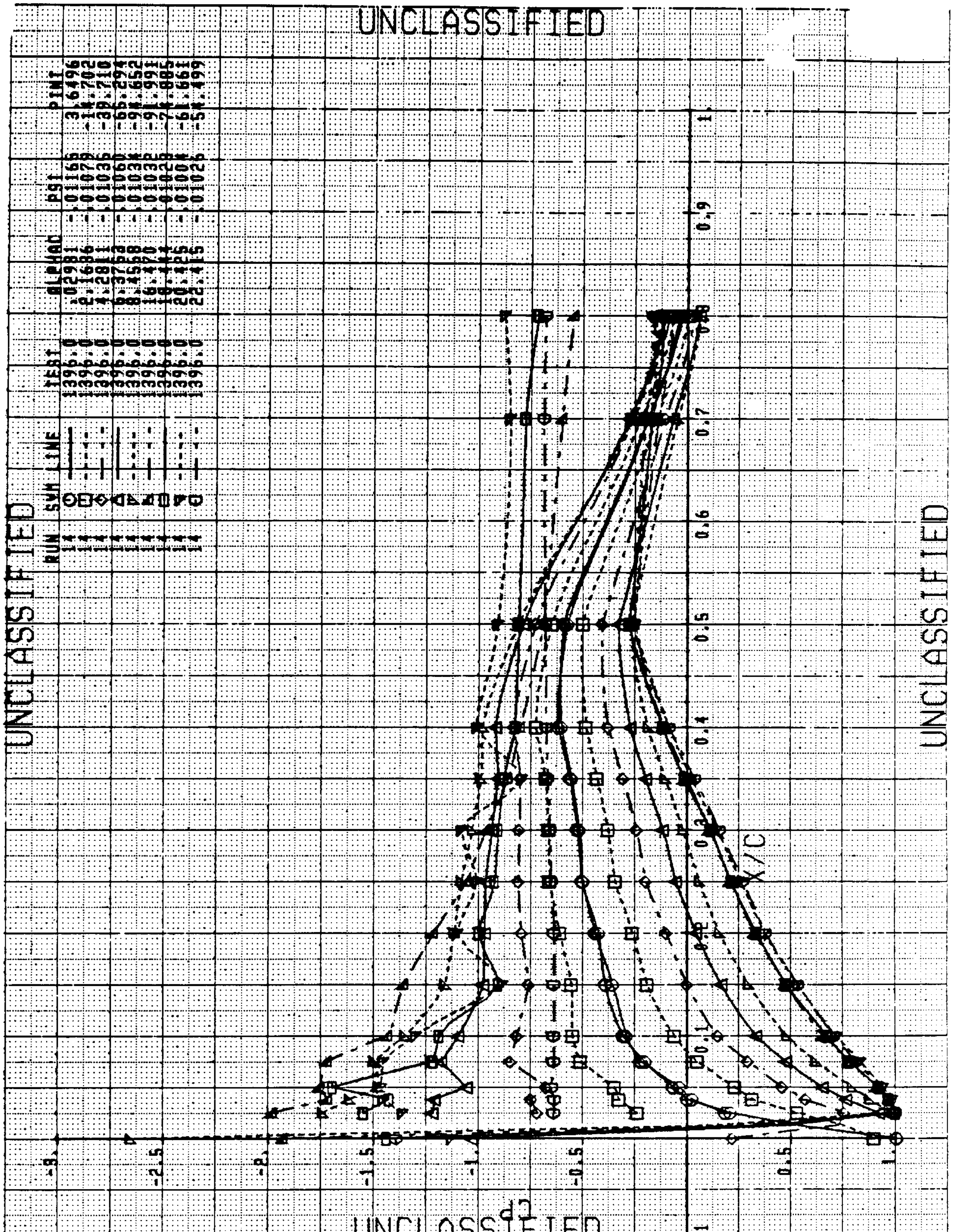

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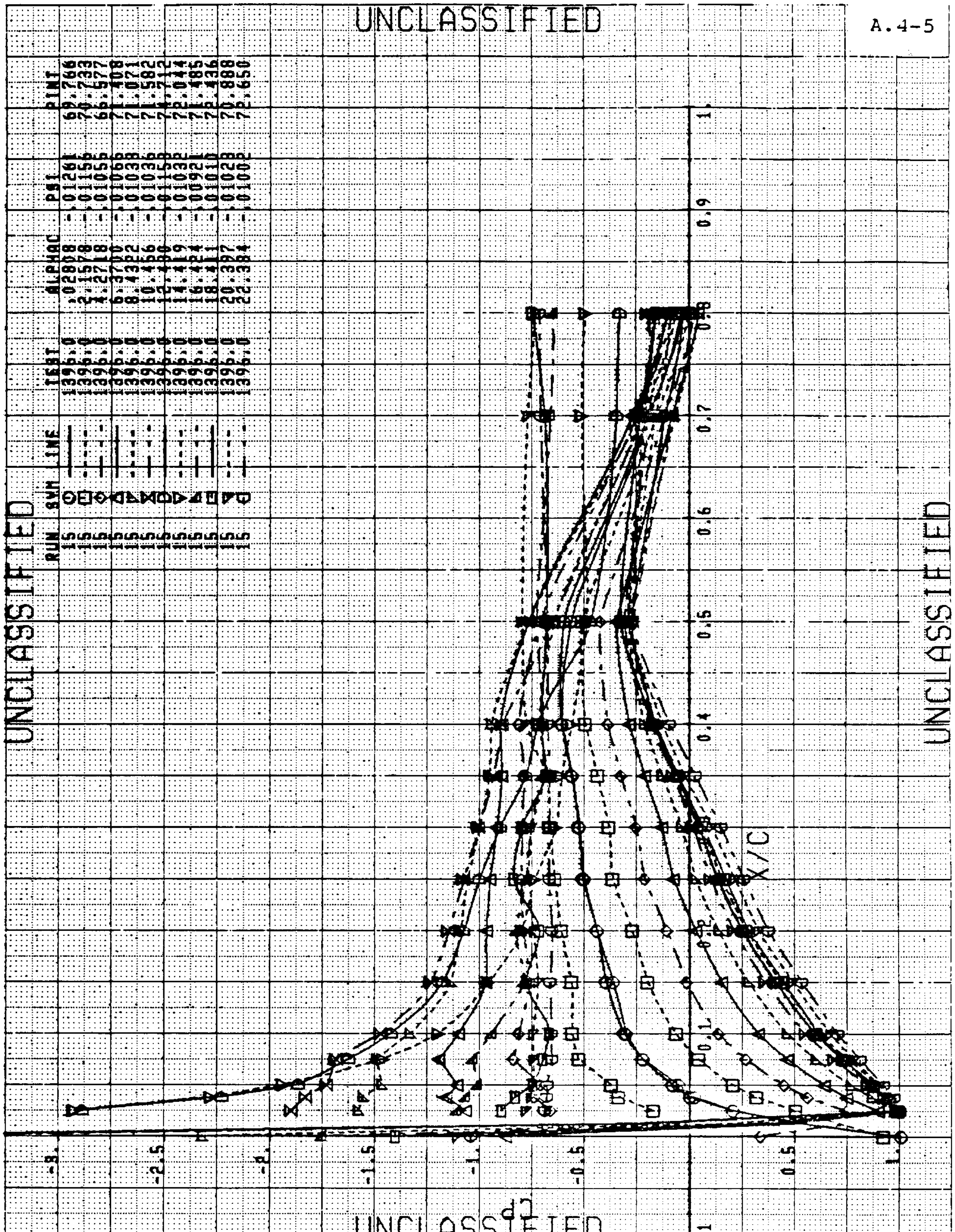

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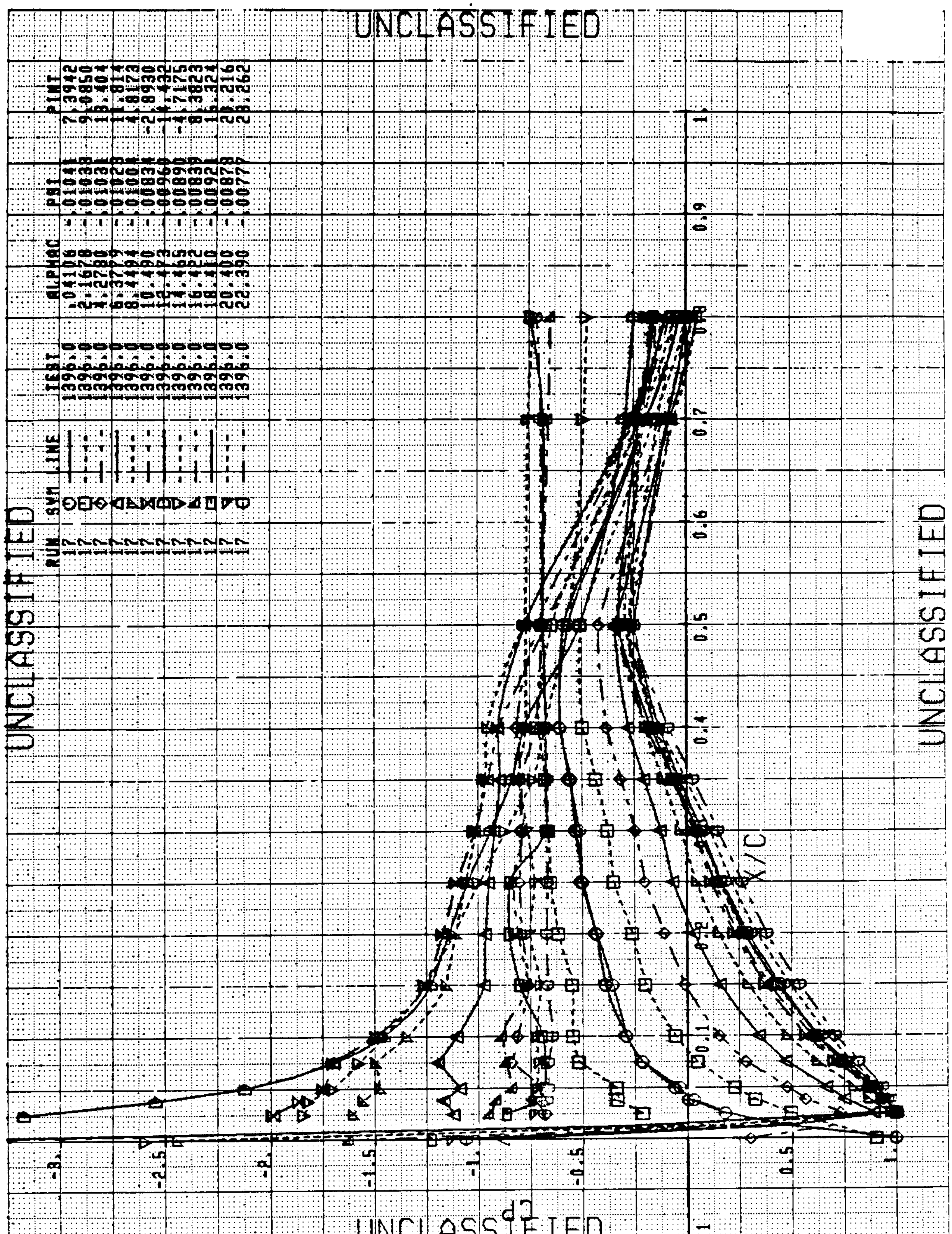
APR					UW AERO LABORATORY	PAGE

A.4-6



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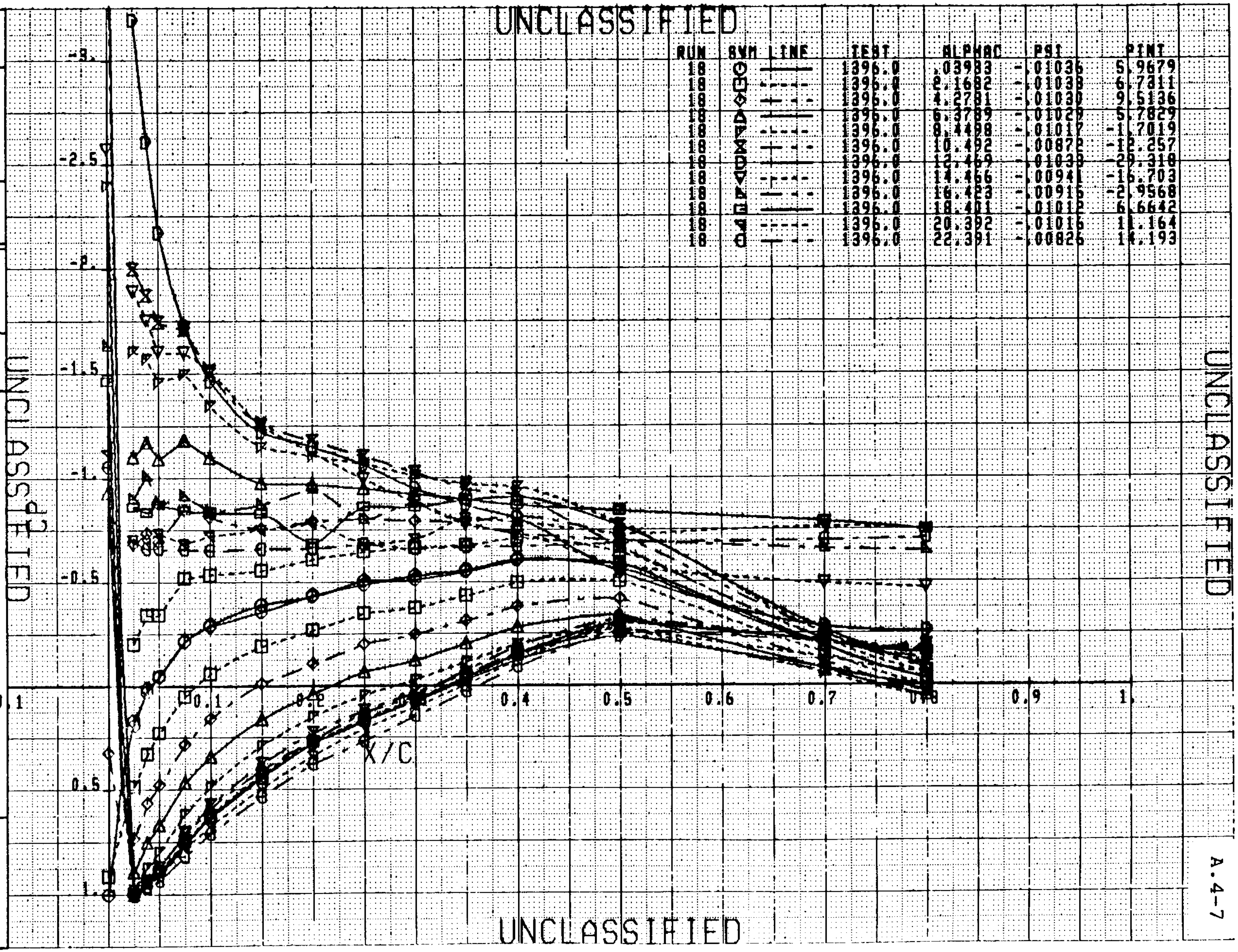

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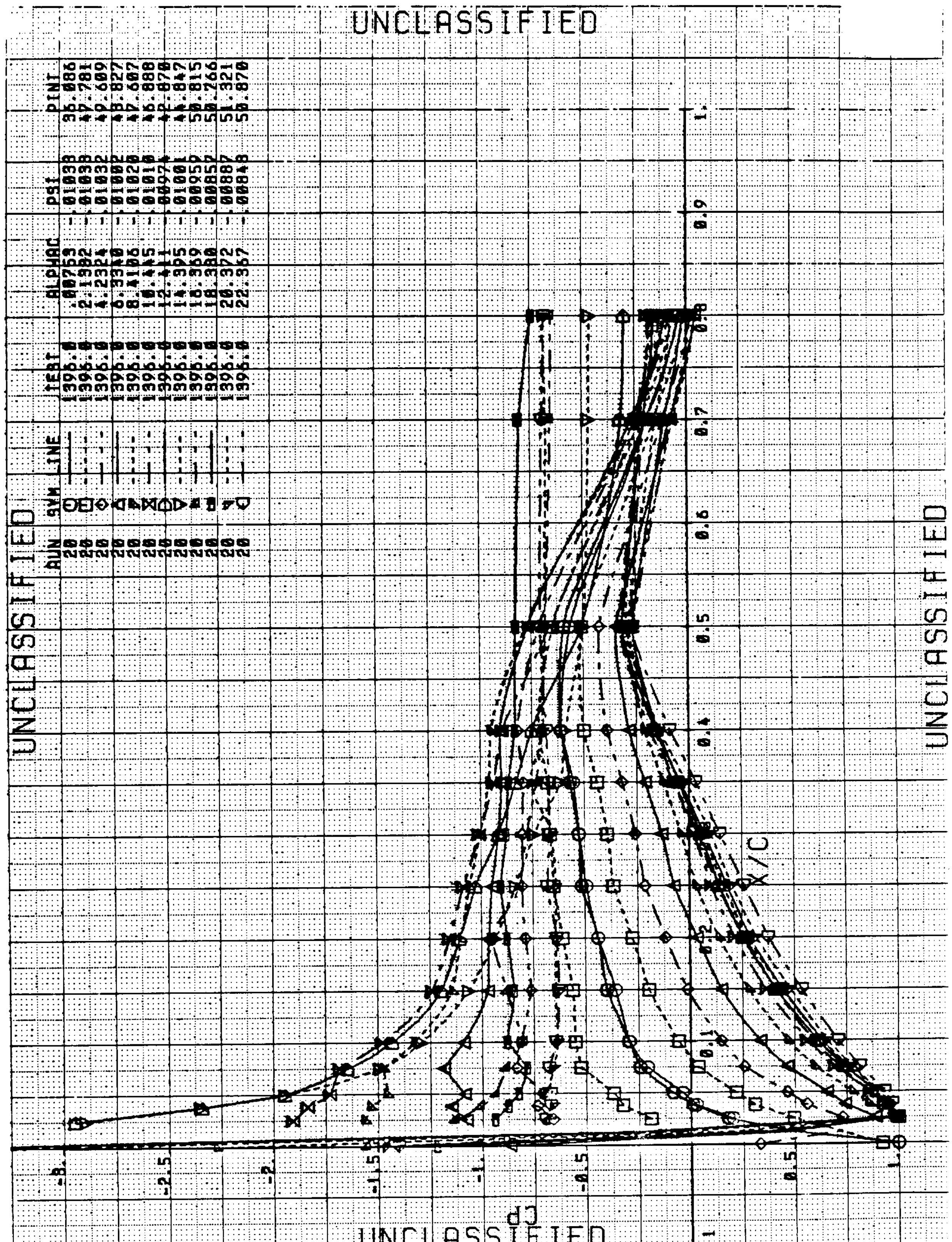

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1850 AIRFOIL

UW AERO LABORATORY

UW1396

FIGURE

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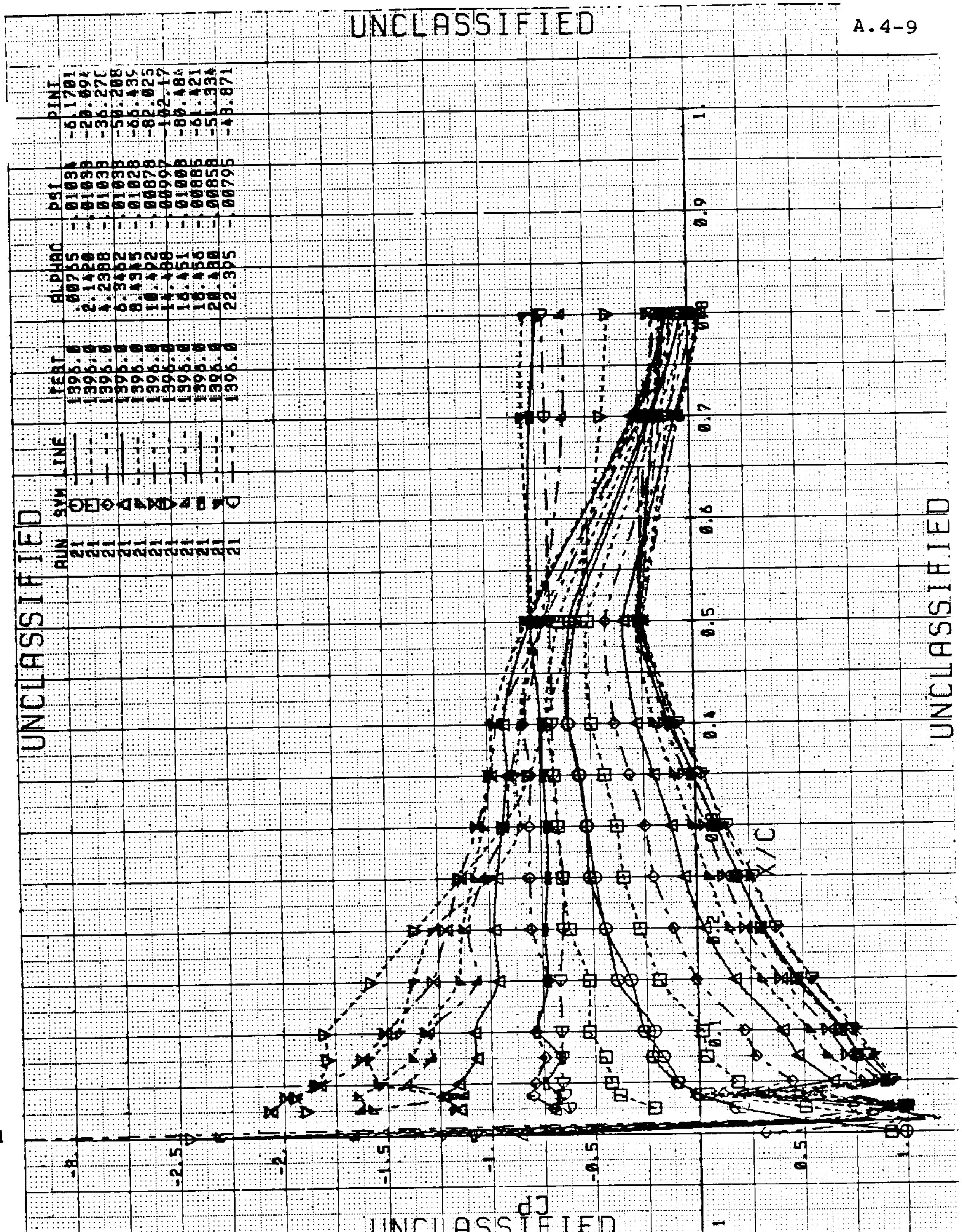

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APR					UW AERO LABORATORY	PAGE

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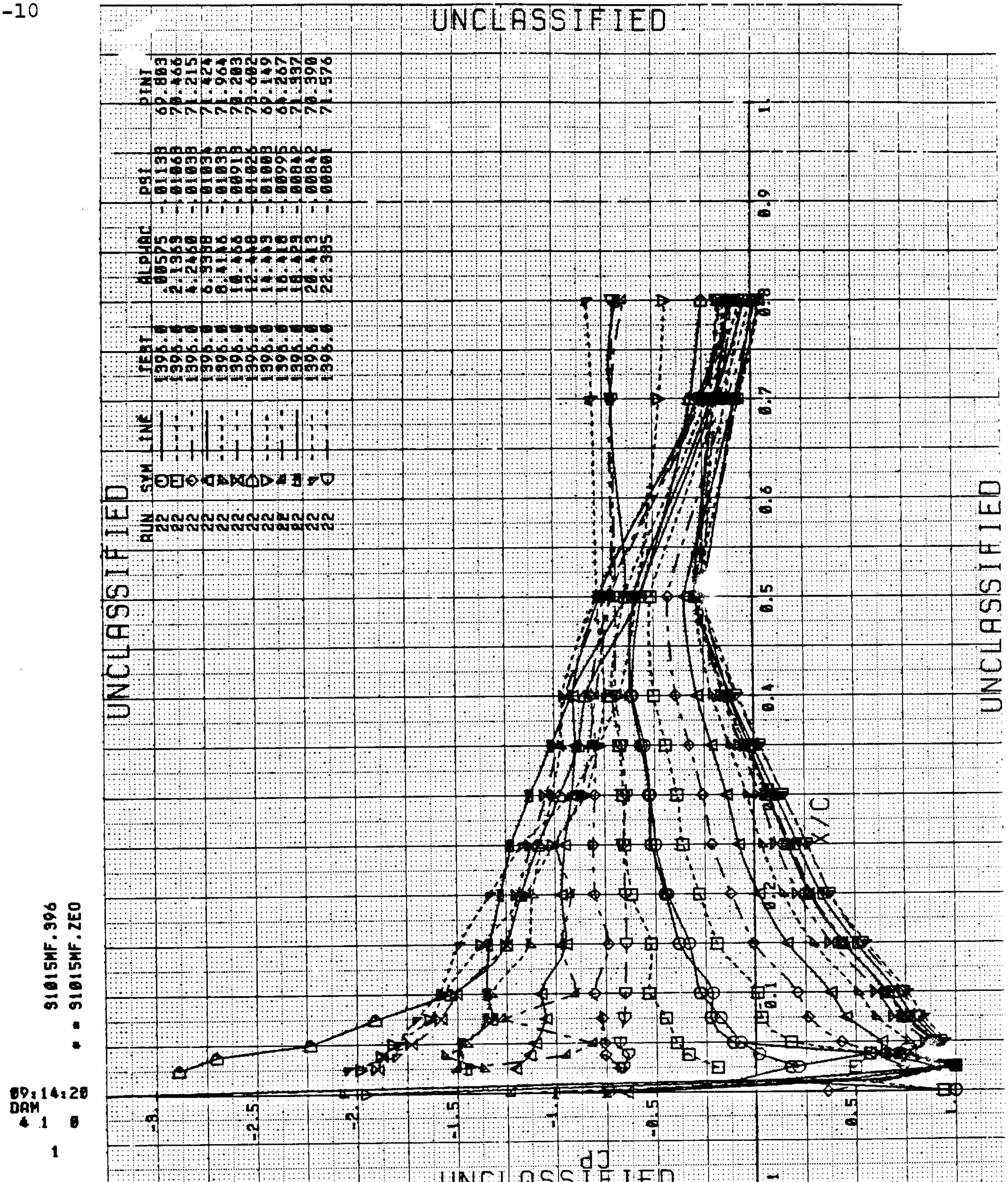

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1850 AIRFOIL

UW AERO LABORATORY

UW1396

FIGURE

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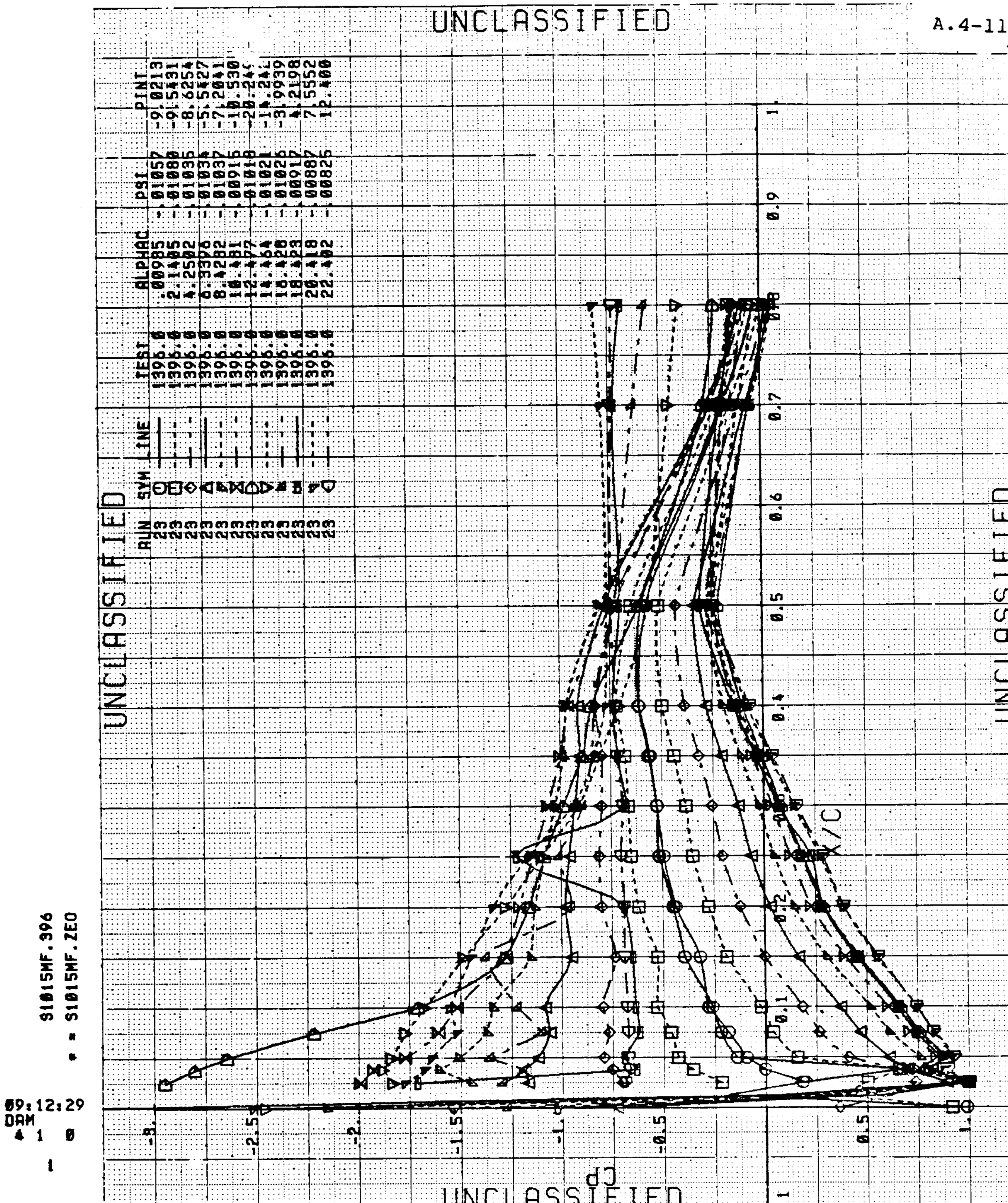

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APR					1850 AIRFOIL
APR					UW AERO LABORATORY
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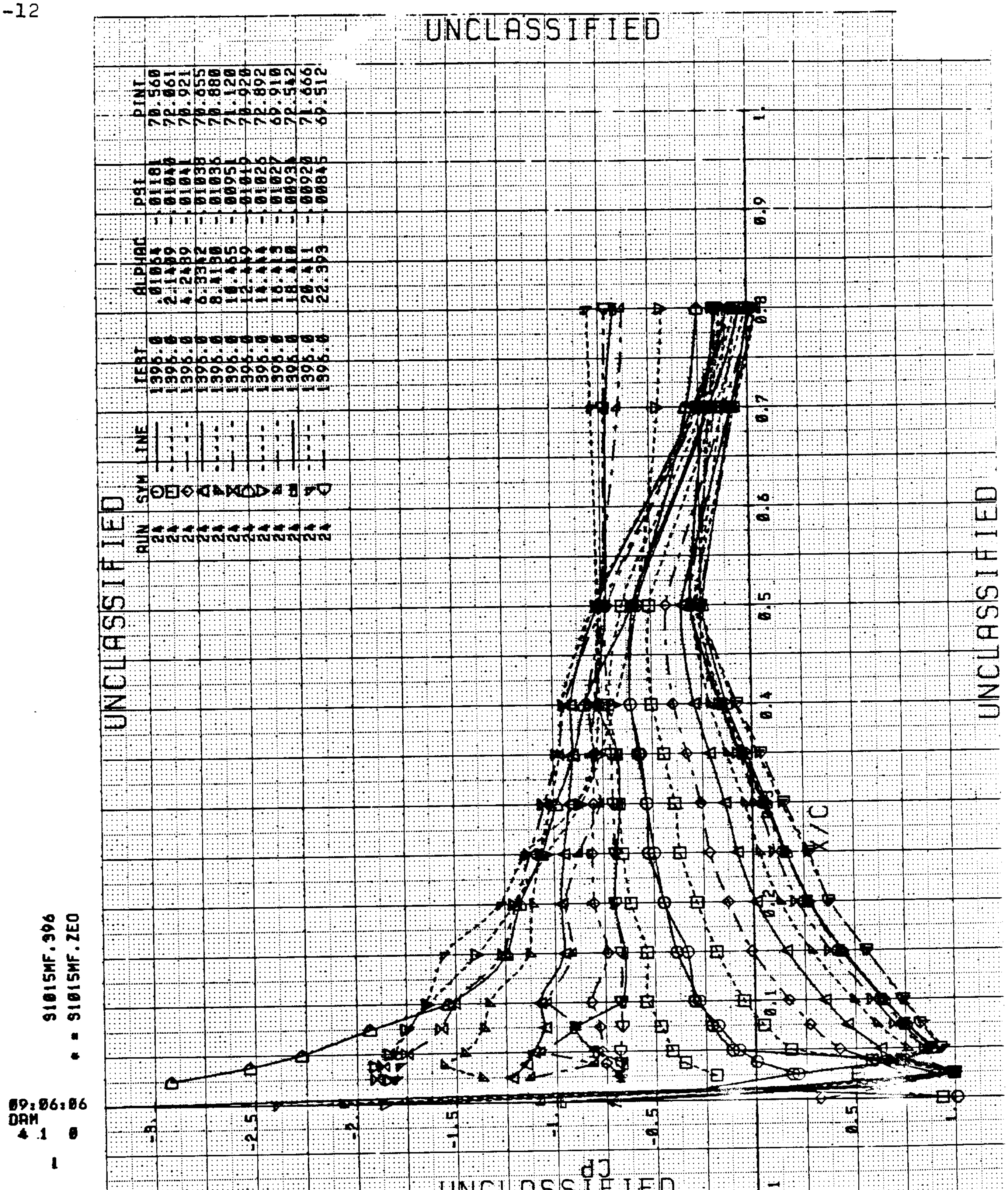

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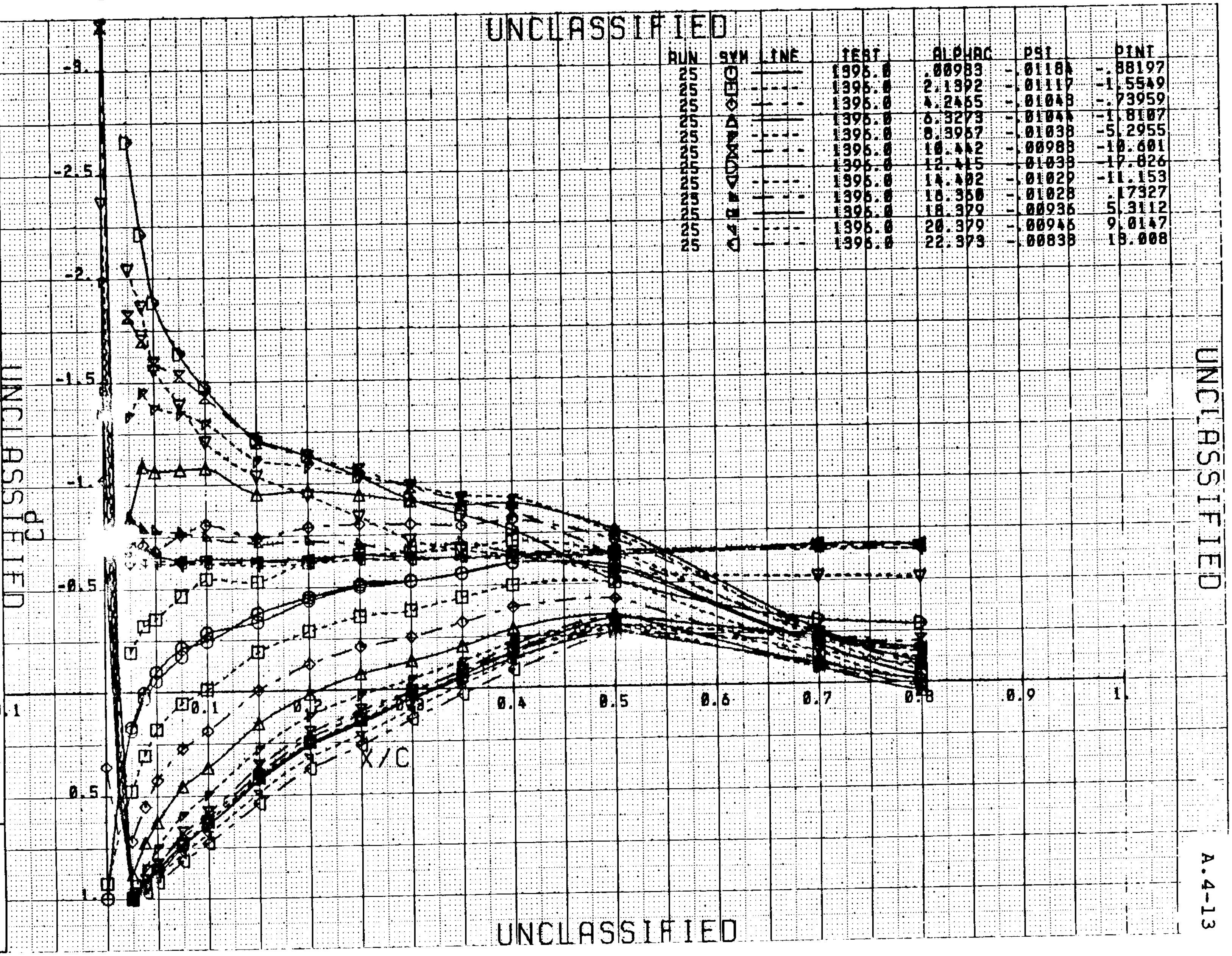

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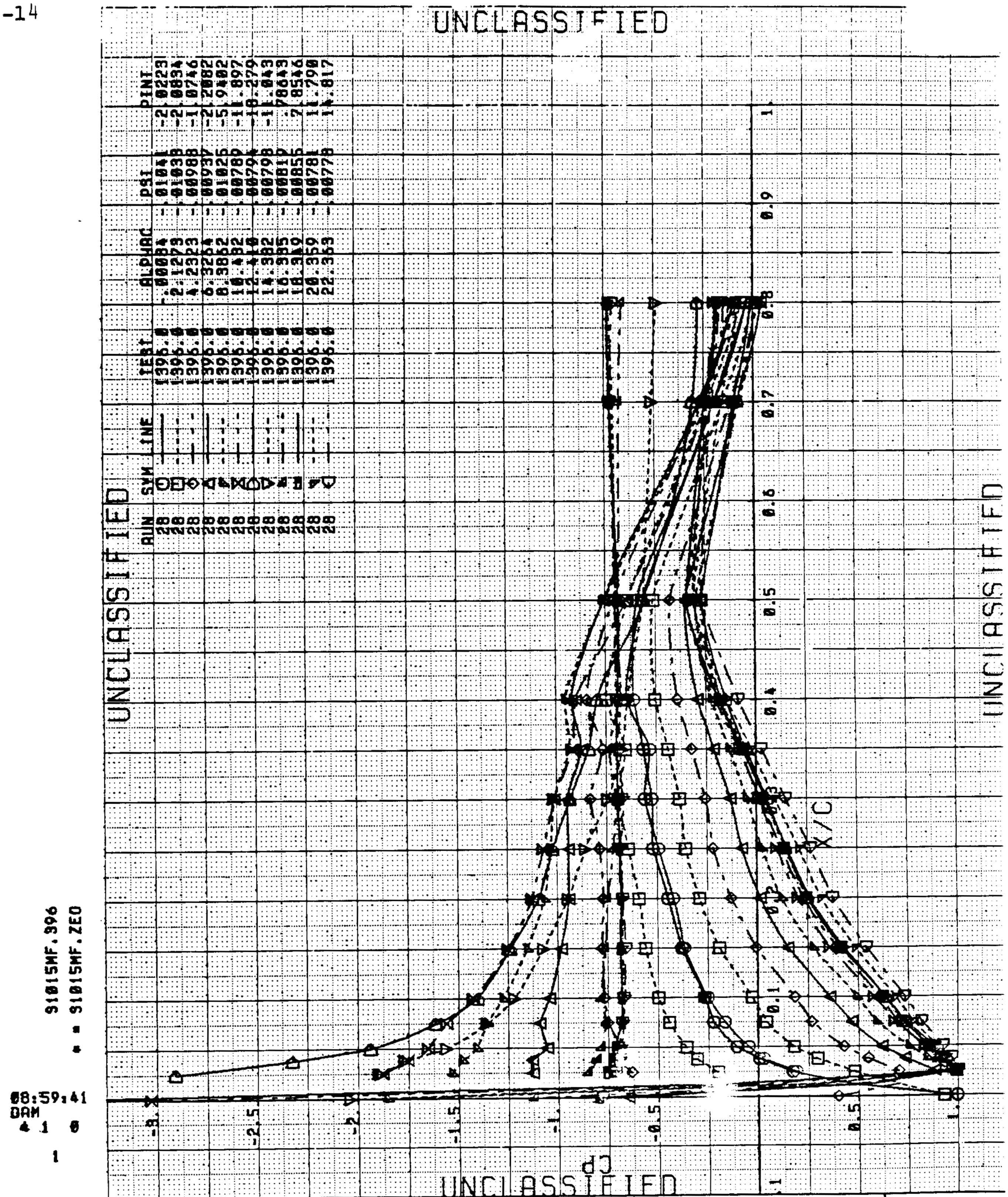
APR				UW AERO LABORATORY	PAGE



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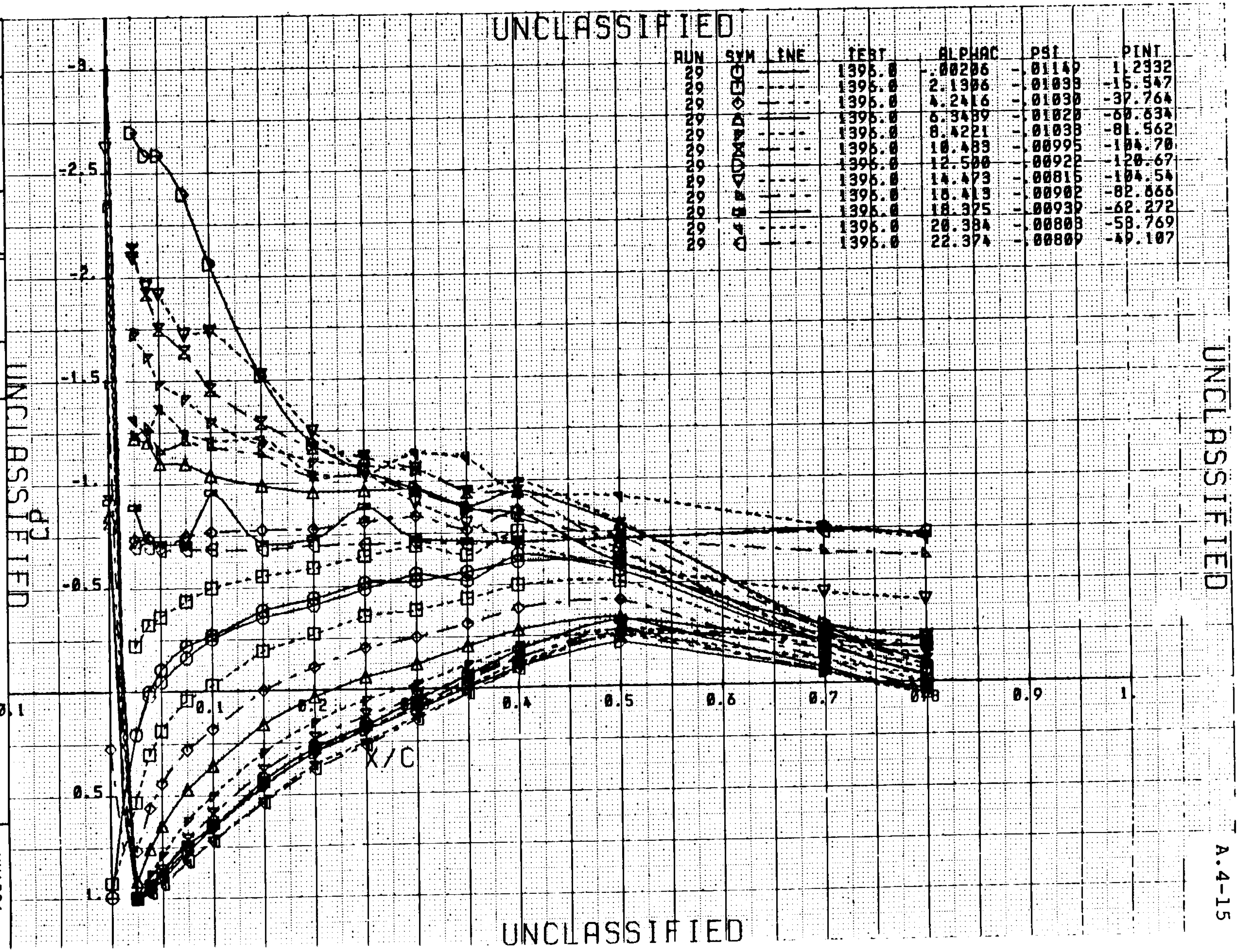

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1850 AIRFOIL

UW AERO LABORATORY

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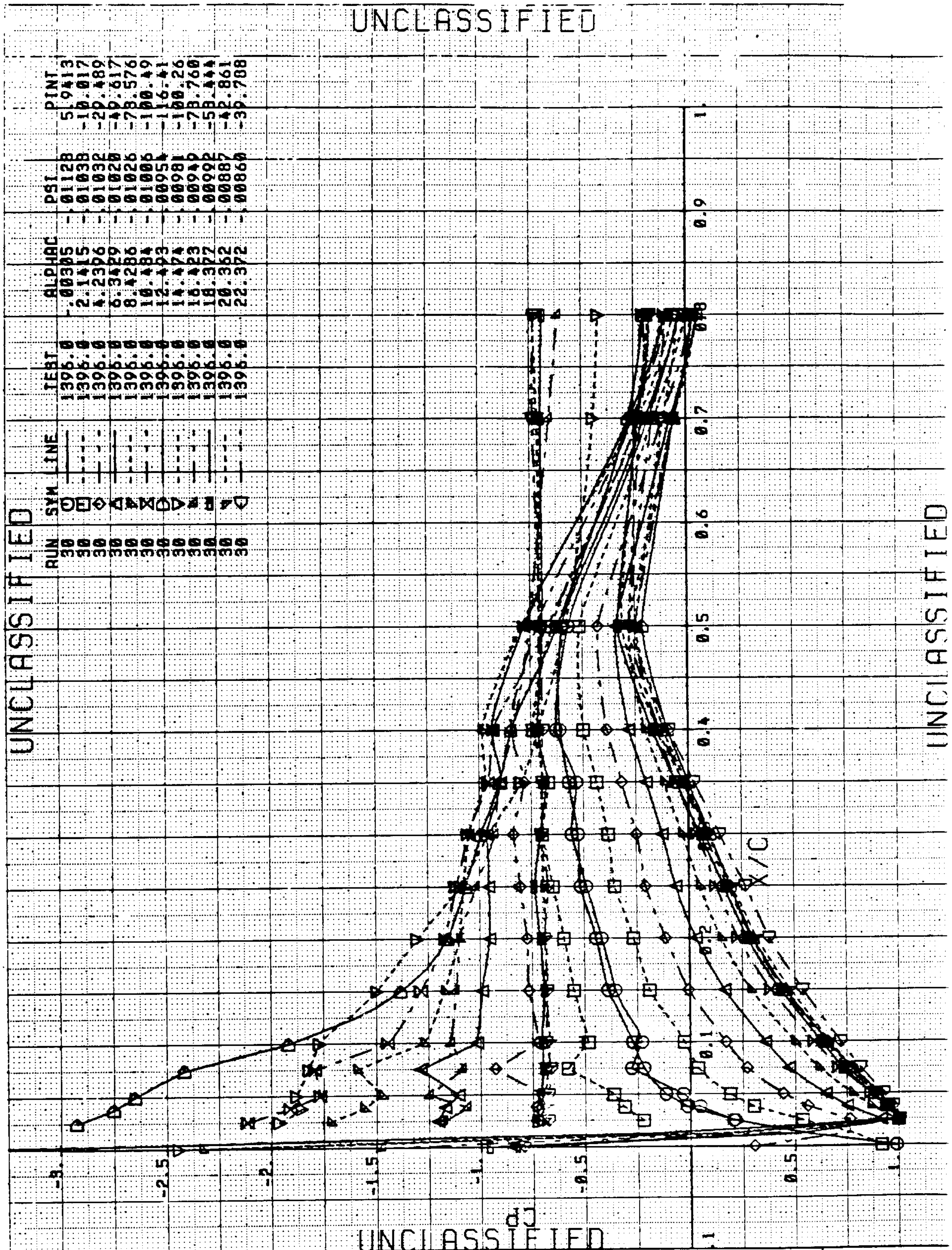

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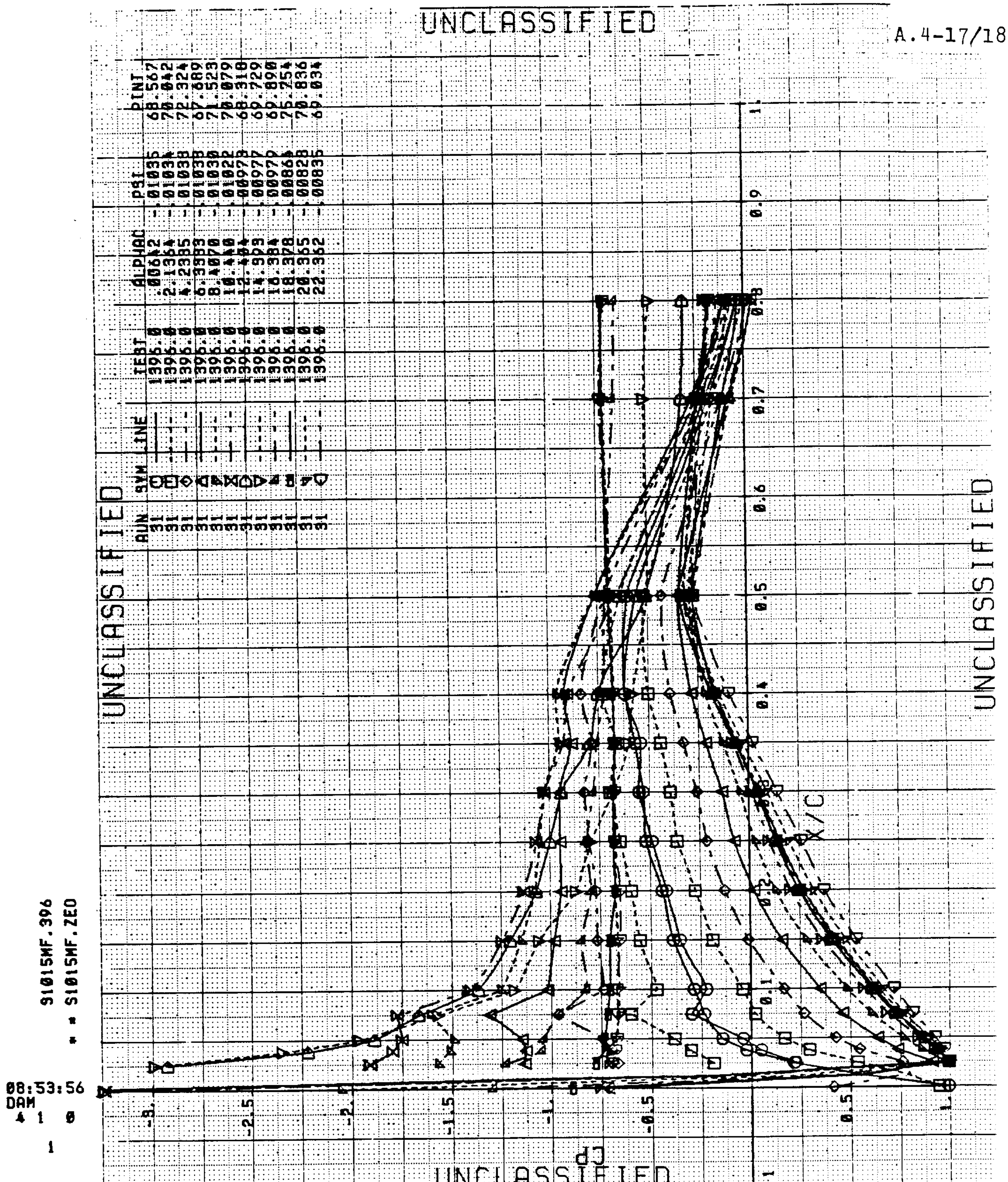

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